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Optical quality assessment of rigid endoscopes during clinical lifetime

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ABSTRACT

An endoscope test bench is presented to test the optical quality of endoscopes on a regular basis to assure optimal image quality during surgery. A power LED and a photo diode are used to measure the transmission of the illumination fibers. Captures of target images displayed on a LCD screen as seen through the endoscope with a high resolution camera are analyzed to determine the contrast for different spatial line pairs. Transmission and contrast plots are compared to reference data to determine whether an endoscope is still acceptable for clinical application. Results show that endoscopes degrade gradually but steadily over time. In time a large database of various types of endoscope will be built to fine-tune the criteria for approval or rejection of the endoscopes.

Keywords: Endoscopy, quality assurance, contrast graph.

1. INTRODUCTION

Engineers of the department of medical technology are frequently confronted with questions from clinicians that something is wrong with an endoscope, for example, that the image is “bad” or that there is insufficient light. In combination with endoscope cameras, the problem is more complex since the image quality can be related to one of the components in the ‘endoscope chain’: The light source, the fiber light cable, the endoscope, the camera, the camera unit or the video screen. To assess the quality of each component in this chain, various measurements are used:

- The light source slowly degrades, but becomes unusable after its factory-defined life time. This can be checked with a lux or power meter.
- Fiber light cables can be checked with simple device consisting of a small LED and photo diode. Cables with a transmission below a certain threshold are rejected.
- The camera and camera unit are electronic devices which could gradually deteriorate but also become defective abruptly showing missing pixels, missing color bands, increased noise etc. This can be determined visually.
- The video screen can be calibrated with a monitor calibration tool. When the calibration can not be performed within specifications, the screen needs to repaired or replaced.
- The endoscope is the most fragile and complicated part as various defects may occur increasing over time[1]. As it is sterilized (either with steam at 134 ºC or in a ‘disinfector’ at 60 ºC with cleaning solutions and disinfectants) before each clinical procedure, glue and lens coating change in consistency and color. Also improper handling of the endoscope may lead to breakage or glass slivers of the lenses or bending of the tube (Figure 1). In addition, fluoroscopy leads to change in imaging properties of the lens coatings as they become more yellowish over time and more opaque.

As the quality of the endoscope is often difficult to quantify visually by the naked eye, we have developed a test bench to determine the optical quality of an endoscope in a quantitative way. Its main design goal was to give a quick answer on the question whether the optical quality of the endoscope would still be suited for clinical use. In this paper we will present our progress in achieving this goal.

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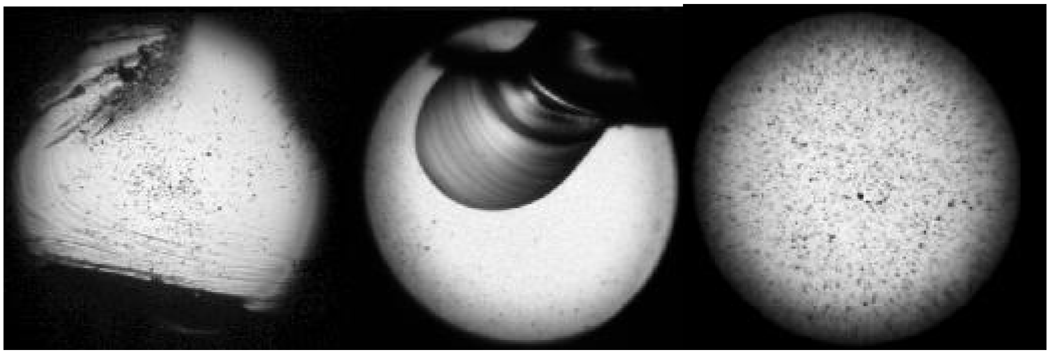

Figure 1 Types of damage to endoscope lenses: Lens break, sliver, water vapor. (Courtesy Storz Germany)[1].

2. MATERIALS & METHODS

An endoscope is tested in two steps. In the first step, the illumination fibers of the endoscope are tested by measuring the amount of light coming through the illumination fibers. In the second step, captures with a digital camera are made of target images displayed through the endoscope and analyzed in a computer system. This computer system puts the results in a database to track the optical quality of different endoscopes over time.

2.1 Transmission measurement illumination fibers

The transmission of the illumination fibers is determined by measuring how much light from a high power LED is coming through the illumination fibers of the endoscope and projected on a photo diode (Figure 2)[2, 3]. The signal from the photo diode is amplified and sampled with an analog digital converter and transferred into the computer. This measurement value is defined as the 100% value and stored in a database together with its day of measurement to track changes in transmission values over time.

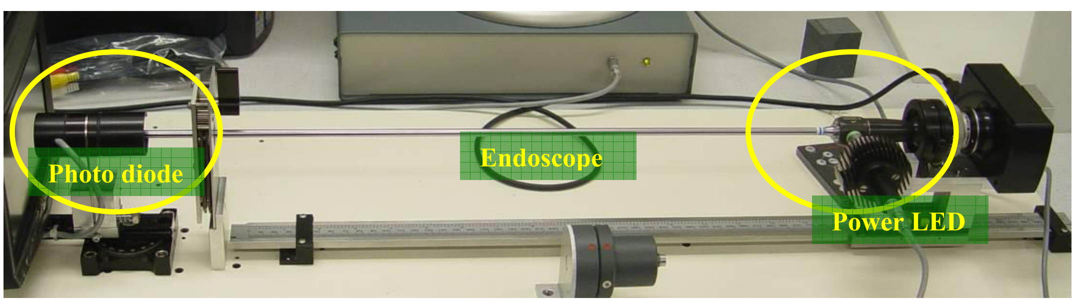

Figure 2 Measurement transmission illumination fibers.

2.2 Measurement imaging pathway

The imaging pathway of the endoscope is checked by displaying test targets on a liquid crystal display (LCD) and by grabbing the images seen by the endoscope using a high resolution USB2.0 camera. The use of a LCD has a great advantage over fixed targets like photographic slides or on cardboard in that the targets can be changed electronically quickly and be replaced with a high accuracy. A disadvantage is the relative low intensity of the LCD by which long integration times (400 ms) of the camera are needed. This requires also adequate shielding from surrounding light as light bulbs and neon lights give strong reflections on the LCD.

The following targets are displayed on the LCD: A black and a white target are shown to determine the background and foreground level of the endoscope. Blocked patterns are used for calculating distortion or seeing local abnormalities. Line patterns are used to calculate contrast plots, contrast as a function of spatial frequency.

2.2.1 Calculation of contrast plots

Contrast plots are used as the main measure to determine the quality of the imaging pathway. It is designed to give the contrast for different spatial line frequencies. It is expected that when the imaging pathway becomes less clear, the contrast drops for higher frequencies. The contrast for a captured image of a spatial line pattern is calculated by determining the distance between the histogram peaks of the white and black lines.

2.3 Mechanical considerations

As the optical measurements of the endoscopes need to have a high reproducibility over time, high mechanical stability is required of the endoscope test bench. This is somewhat contradictory to the demand that the bench also needs to accommodate for a large variety of endoscopes, from 50 cm long and 10 mm thick laparoscopes to 10 cm short 4 mm ENT endoscopes. Also endoscopes have a large variety in view angles (0, 30, 45, 70, 90, 120 degrees). This is solved by using an optical rail which can be rotated to the appropriate view angle, by mounting the camera directly on an electronic ruler to accurately reposition the tip of the endoscope (Figure 3). To block background light, a black covering has been designed over the tip of the endoscope.

2.4 Software

Special software has been developed to read out the AD values of the photo diode and process the digital image captures. Captured images and measurement values are stored in a database to track the optical quality of the endoscope over time. In addition to showing plots of the transmission of the illumination fibers and the contrast of the imaging pathway, the system also enables visual comparison of images captured at different time points of the same endoscope or of endoscopes of the same type. There are two options in doing the comparison. The first option is to compare with the first measurements ever done with an endoscope. In this way, one can check whether the optical quality of newly bought endoscopes correspond to what has been bought before. The second option is to compare with the last measurements ever done with an endoscope. In this way, one can check whether one rejects endoscopes on the same criteria as one has done in the past.

Figure 3 Overview of endoscope test bench.

3. RESULTS

Our first measurements concentrate on showing that the system is capable to reproducible measure the optical quality of endoscopes. Finally, we show our first results in testing the optical quality of endoscopes in our hospital.

3.1 Reproducibility of measurement

To test the reproducibility of the endoscope measurements, a zero degree, 4 mm endoscope of 50 cm length has been tested five times. The resulting contrast and transmission plots are shown in Figure 4. It demonstrates that the reproducibility is high enough to enable quantitative comparison of the optical quality of endoscopes at different phases in its lifetime, or between endoscopes of the same type.

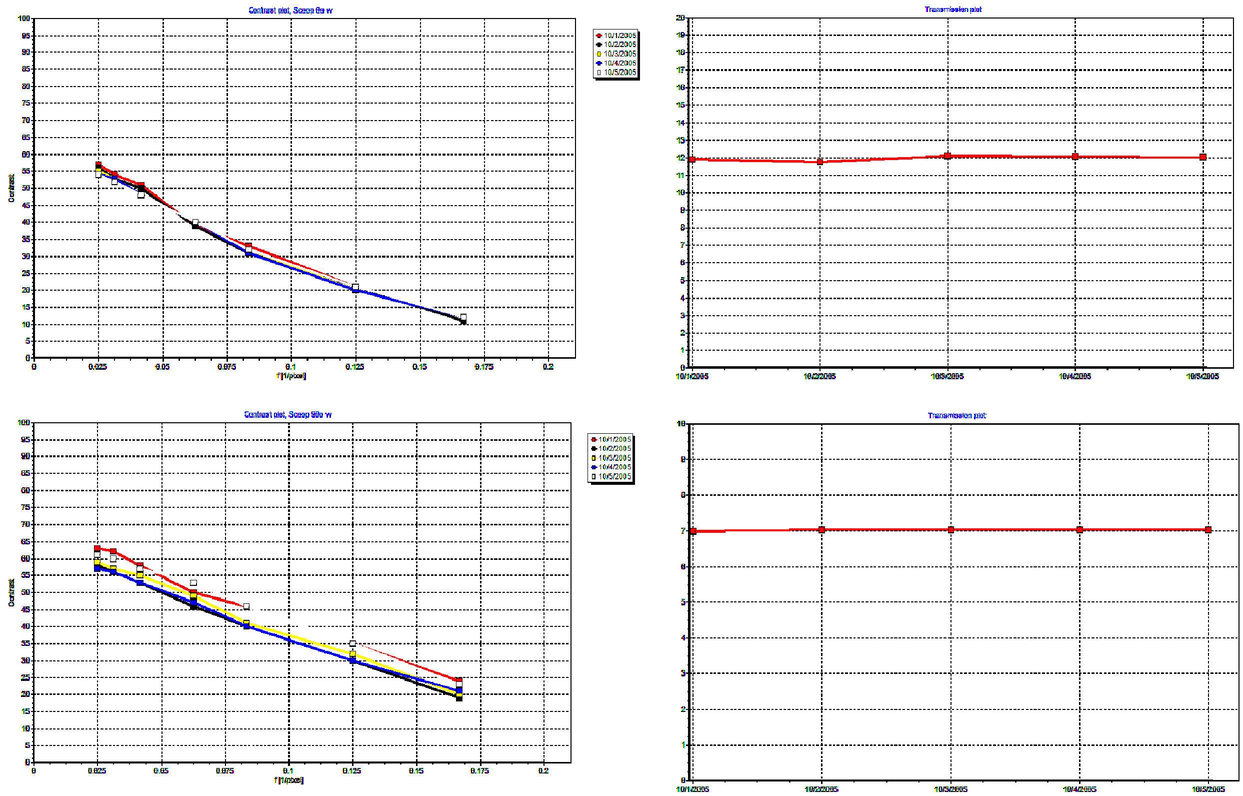

Figure 4 Reproducibility of contrast plots (left) and illumination fiber transmission (right) of five endoscope measurements by repeatable repositioning endoscope, target LCD display angle and camera. Upper row: endoscope with 0° view angle, bottom row: endoscope with 90° view angle.

3.2 Clinical results

As an illustration of what can be expected with clinically used endoscopes, we measured at two dates the optical characteristics of 8 arthroscopes and one ENT endoscope: 4 mm rigid endoscopes of 175 mm in length and a view angle of 30 degrees (Figure 5). When looking at the contrast plots, one sees a large variation in results. The ENT endoscope was so bad that we returned it for repair. The variation of the other endoscopes is currently accepted as we do not know yet what is clinically acceptable. Looking at the transmission plots, we see that the transmission measurements correspond well over time. Five endoscopes had such low transmission that they hardly illuminate the cavity. Still, they are still being used in clinical practice… After these measurements, they have been sent in for repair.

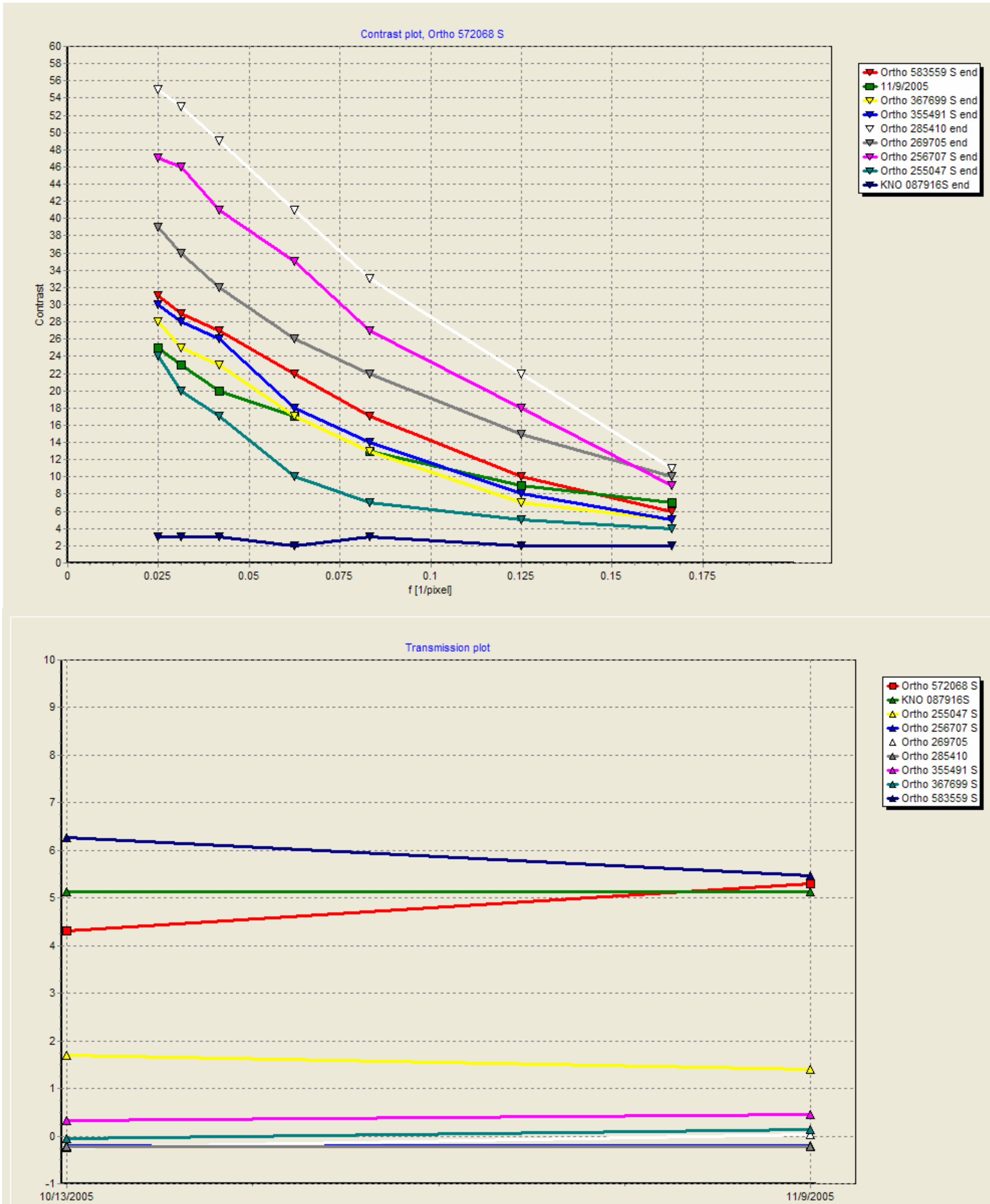

Figure 5 Contrast plots of eight different endoscopes of type Storz 28721 BWA at several stages of usage. The transmission of the illumination fibers of endoscopes with numbers 285410, 355491, and 367699 are so low, that they should be removed from clinical use.

4. DISCUSSION

We presented a test bench to determine the optical quality of endoscopes during its clinical lifetime. The test bench is optimized for a minimal number of manual steps, so that it can be performed in a minute. The test bench has been designed such that measurements can be performed with high reproducibility. Although the system is well suited for clinical usage, there are a few remarks one should be aware of:
The measurement values can not be interpreted as absolute values as the system is not a real endoscope system where every component optimally fits to another. For example, the high power LED has a large emission angle by which it is not optimally coupled into the fiber bundle, so a 100% transmission may never be possible. Also, the focus of the adapter between the endoscope and the camera is usually set such that an optimal image is created from the body cavity while the focus is fixed in the test bench as it influences the contrast values directly. The relative values can be used to compare one endoscope type during its lifetime or between endoscopes of the same type for acceptance after being bought or for rejection at the end of its lifetime.
The criteria to accept an endoscope after acquirement or to reject it at the end of its life-time depend not only on degree of degradation but also on the clinical application it is being used for. The database so also contains these relevant data to determine acceptance and rejection criteria.
With this test bench it is now possible to obtain quantitative data on the quality of endoscopes. However, it is still under discussion where and by whom the test will be performed in the clinical logistic chain: OR -> CSU -> OR. Should people from the OR check the endoscopes or people from the CSU? As the latter often claim to be responsible only for sterilization and not for the quality of clinical instruments, the department of Medical Technology might play the key role in the quality chain. Another question is at which frequency the endoscopes need to be checked: Do they deteriorate gradually or with sudden jumps. In the near future, these questions may be answered with the help of our test bench.

On the world-wide-web other solutions can be found to test endoscopes. One solution is the EndoTester found the website of national instruments[4.] Differences with our system are that this system is meant for fiber-optic endoscopes, it uses a standard video camera and used fixed test targets instead of LCD. Another solution is the Endoscope Testing System from Automation Engineering Incorporated[5] of which the technical details are not described.

5. CONCLUSIONS

In conclusion, the endoscope test bench described in this paper, has enough stability for quantitative assessment of the optical quality of endoscopes, for both the illumination pathway with light source and detector as the imaging pathway with flexible test targets and a digital camera. The first measurements show a large variation in optical quality of clinically used endoscopes. As the rejection criteria of the optical quality of endoscopes are still undetermined, only the worst endoscopes were send in for repair.
In future more results will be collected on clinically used endoscopes. Tests on new endoscopes will help to determine the acceptation criteria, while periodic tests on clinically used endoscopes and feedback from the surgical field will help to establish rejection criteria.

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