Axel Boese*, Akhil Karthasseril Sivankutty and Michael Friebe

Evaluation and image quality comparison of ultra-thin fibre endoscopes for vascular endoscopy

Abstract: Medical applications like vascular endoscopy can provide additional diagnostic value for future procedures [1]. For these applications an optimal compromise between image quality and fibre flexibility has to be identified. Image quality of endoscopes is normally estimated using flat test objects or charts. For the application of vascular endoscopy a tubular test set up seems to be more beneficial. We compare three fibre endoscopes with different diameters and number of integrated fibre according to image quality and flexibility. Based on the results a recommendation for possible applications in vascular endoscopy is given.

Keywords: Fibre endoscope, image quality comparison, vascular endoscopy

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1 Introduction

Minimal invasive image guided interventions are increasing. Besides external imaging like X-ray, optical imaging based on endoscopes is a widely used image guidance modality. Endoscopes are used invasively and therefore require small dimensions to reduce traumata on access path. Thin diameters and flexible structures are desirable and clinically beneficial. Fibre endoscopes provide these benefits, but the image quality and diameter depends on the number of integrated fibres. But not every application requires high quality imaging, sometimes flexibility and small dimensions are more important. We evaluated the quality of optical images acquired with three different fibre endoscopes (Micro- Epsilon 30.000px, D 1,5mm; Micro- Epsilon 10.000px, D 1,0mm; KARL STORZ prototype 5.000px, 0,5mm) to test their usability for new clinical applications like vascular endoscopy [2], [3].

***Corresponding author: Axel Boese:** Otto-von-Guericke-University Magdeburg, IMT-INKA, Universitätsplatz 2, 39106 Magdeburg, Germany, e-mail: axel.boese@ovgu.de
Akhil Karthasseril Sivankutty, Michael Friebe: Otto-von-Guericke-University Magdeburg, IMT-INKA, Universitätsplatz 2, 39106 Magdeburg, Germany, e-mail: ksakhilofficial@gmail.com, michael.friebe@ovgu.de

2 Materials and methods

For the evaluation, three tubular phantoms were developed. Phantom 1 includes a line pattern at the end and an enlarging line pattern on the side wall. The line patterns are based on the Koren lens test chart [4] that is used for sharpness testing in photography (see **Figure** f). The second phantom is based on a standard eye test chart. Letters in decreasing size were included. The third phantom offers a colour field on the end and changing colours on the side wall. The patterns were integrated in the corpus of three syringes with an inner diameter of 8 mm and a length of 55 mm (see **Figure** c). These syringes are mimicking a tubular structure comparable to a human blood vessel. A guidance tool was designed to ensure a centric placement of the fibres in the phantoms. The fibres were fixed with the tip inside the guidance tool. A measurement scale on the outside of the guidance tool allows a reproducible placement inside the phantoms (see **Figure** d). The endoscopes were connected to a standard endoscopic imaging system (EVIS EXERA III + CH-S190-XZ camera module, all Olympus, Germany) (see **Figure** a+b). White balance check was performed before image acquisition. The phantoms were imaged at prior defined positions of the guiding tool inside the phantoms. The resulting images were rated subjectively and analysed using ImageJ. The real number of pixels and size of the resulting images were evaluated for each fibre endoscope. The dimensions of separately distinguishable lines were determined. For investigation of colour reproducibility the RGB values of the red, green and dark blue colour field were identified using the Photoshop eyedropper tool and compared to the RGB values of the colour fields of the original pattern.

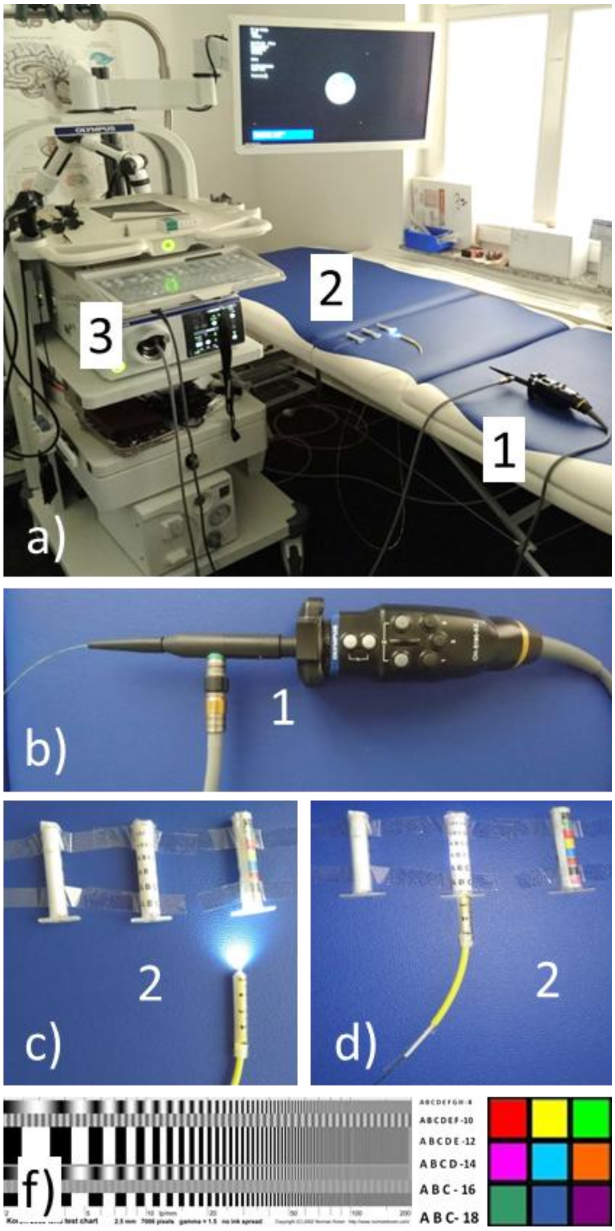

Figure 1: Experimental set up for evaluation and image quality of endoscopic fibres, 1 endoscope and camera, 2 phantoms, 3 imaging system, a) general set up, b) camera, fibre and light cable, c) +d) phantoms and guidance tool with integrated fibre endoscope

Since flexibility is an important factor for clinical applications like vascular endoscopy, the minimal achievable bending radius was evaluated. Therefor a curvature phantom (M3DP, Magdeburg, Germany) was used. **Figure 1** illustrates the results for a 1,0 mm fibre with 10.000px, 0,8mm fibre with 7000px and 0,5mm fibre (5000px). The 1,5mm fibre which is not shown in **Figure 1** achieves a bending radius of 50 mm.

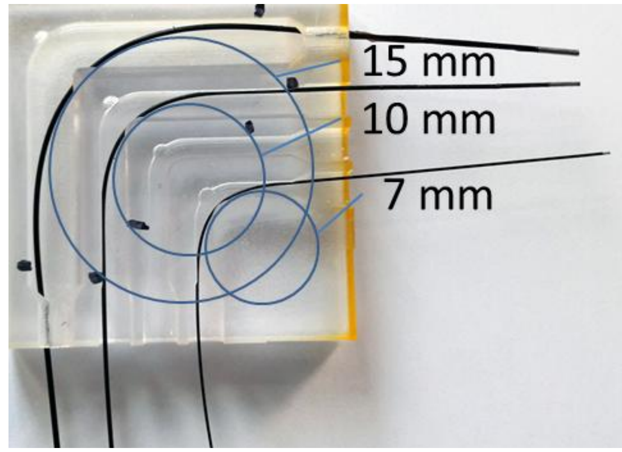

Figure 2: Evaluation of bending radius of endoscopic fibres: fibre diameter top 1mm, middle 0,8mm, bottom 0,5mm

3 Results

Images were acquired in four different distances form entry point in every phantom and with every fibre. The results of the subjective rating of image quality are as expected. The subjective impression of image quality of the 30.000px fibre is high, for 10.000px it is medium and for 5000px it apears poor. The diameter of the displayed field of view is 200mm for the 30.000px fibre, 160mm for the 10.000px fibre and 100mm for the 5.000px (see **Figure 1**). The overall image size is 610x380mm. The displayed numbers of pixel in the resulting image window are shown in **Table** . Number of pixel is increasing nearly linear with increase of number of fibres. Line dimension of 0,15mm, 0,35mm and 1mm are distinguishable using these endoscopes (**Table**).

Table 1: Comparison of number of displayed pixel and distinguishable line dimension

Fibre endoscope	Number of pixel	Distinguishable line dimension
ST 5000	72348	1 mm
ME 10000	164388	0.35 mm
ME 30000	381584	0.15 mm

Coloured images were rated subjectively too. All colours appear blurry within the images of the 5.000px fibre. Brightness is higher however in the smallest fibre. The RGB comparison listed in **Table 2** shows higher red and green values for the 5.000px fibre. The 10.000px and 30.000px fibre show higher blue values in the dark blue field.

Table 2: Comparison of R,G,B values for red, green and dark blue pattern of phantom 3

Fibre endoscope	Red R G B	Green R G B	Dark blue R G B
Original image	254 1 0	0 255 1	0 204 255
ST 5000	148 69 59	158 177 79	91 122 148
ME 10000	135 51 48	122 166 78	73 111 157
ME 30000	127 30 27	90 120 73	52 103 163

4 Discussion

Image quality is a significant factor for a valuable diagnosis. The analysis confirmed that image quality is directly related to the number of pixels and the number of fibres used. The ME 30.000px fibre is advantageous over the other fibres in terms of image quality. But the flexibility test has demonstrated the limits in its application. This fibre can produce images of small vascular defects in a high level of detail. According to the achievable bending radius, a fibre of this size and flexibility would be useable in larger straight blood vessels like the aorta, femoral artery brachial artery or for cardiac ablation. The 10.000px fibre still provides a detailed image with sufficient image quality. The flexibility test with a 1mm fibre demonstrated an achievable bending radius of 15mm. This would allow a placement inside middle sized curved vessels like the carotid arteries. The small 0,5 mm 5.000px fibre is significantly more flexible comparable to the body of a micro guide wire. The image quality is low but allows the visualisation of vascular branches or stent struts. According to the flexibility, an application in more distal vessels seems to be possible.

For all mentioned applications a guiding catheter would be mandatory for placement to avoid puncture.

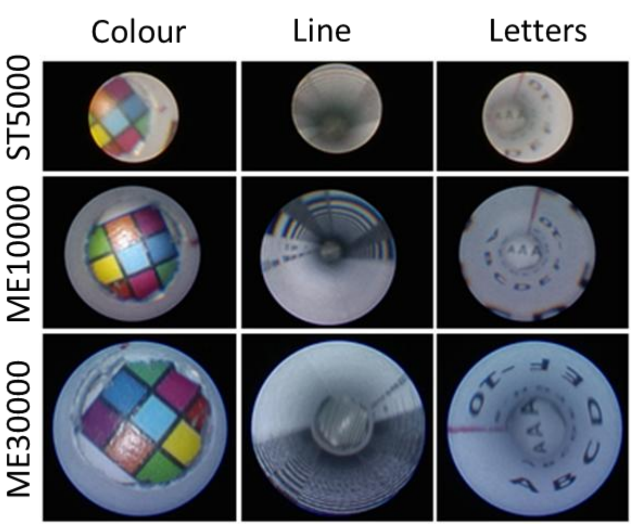

Figure 1: Samples of acquired Images in colour phantom, line phantom and letter phantom; upper row 5.000px fibre, middle row 10.000px fibre, lower row 30.000px fibre

5 Conclusion

According to the findings we conclude that structures of interest of high contrast and within the size of the reported distinguishable lines are detectable in medical application using all of these endoscopes. According to the focussed medical application the diameter of the fibre has to be chosen. As expected, higher number of fibres offers higher image quality. But even the smallest fibre endoscope that was evaluated can offer suitable images of structures in a dimension of below 1 mm.

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