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Optical endovascular imaging combining endoscopy, NBI and OCT, a feasibility study

Abstract: For imaging of the vascular structure, angiography is state of the art. This can be done by contrast enhanced X-Ray, CT or MR imaging. But these modalities typically only show the blood flow and do not allow a depiction of the vasculature itself. To provide information about the vessel walls and plaques narrowing the blood flow, catheter based intra vascular ultrasound or vascular optical coherence tomography can be used. Optical endoscopic imaging is rarely used in vascular diagnosis. But endoscopic imaging can depict superficial inflammations or defects of the intima vessel layer and the real anatomical shape of the inner vasculature e.g. at bifurcations or aneurysms. Since OCT and endoscopic imaging both need a flushing to remove the blood for a short time, a combination of both modalities seems viable. For combining the two modalities, various background studies were performed including the selection of a feasible fibre endoscope, light source and camera system. A new pull-back and flushing device was designed and created for realizing the synchronous image acquisition using the two modalities. For calibration of the system and definition of the pullback and imaging parameters, first tests on artificial phantoms were performed. Then vascular and tissue models were imaged in a combined pullback mode after using the flush for complete blood removal. Endoscopic images were acquired in a video mode. The analysis of the images was done subjectively. As expected, the OCT provided structural information of the wall. The endoscopic images in combination with pullback appear blurry in video mode. The flushing liquid hinders the automatic focusing of the camera. Thus, smaller details could not be identified but bifurcations were visible. Even though the results were not good as expected, the study showed the potential of a bimodal system and addressed the issues faced in the initial implementation.

Keywords: endovascular imaging, endoscopy, OCT, optical coherence tomography, angioscopy

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1 Introduction

Research studies showed, that endovascular visualization as a diagnostic tool can improve prognosis and can be useful in imaging calcifications [1], thrombus [2], plaques [3], and even in stent placement [4]. Conditions which could be the precursors of strokes, aneurysms and embolism can be identified. Visualization of the aorta, coronary artery [4] and peripheral arteries has been performed using angioscopy. Angioscopy using the conventional white light endoscopy (WLI) is one modality for evaluation of the luminal surface by direct visualization of the interior of blood vessels [5]. White light endoscopic systems with high resolution capability offer clear imaging of the vascular surfaces. In combination with narrow band imaging (NBI) the depiction and enhancement of small defects, that can be caused by interventional devices like catheters, guide wires, stents or ablation techniques, seems promising [6] [7]. NBI is an endoscopic imaging technique, where light of specific blue and green wavelengths (415 nm (blue) and 540 nm (green)) is used to enhance structures. WLI + NBI can be used for visualization of the real anatomical shape of a vascular structure (Figure 1).

Figure 1: WLI + NBI of a vessel bifurcation [6]

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With the development of optical coherence tomography (OCT) [8] and intravascular ultrasound (IVUS) [9] it was made easier to visualize structures even inside the vascular wall. OCT has been successfully used in the assessment of stent strut apposition. With lesser penetration depth, OCT provides better image resolution than IVUS but suffers when vessel sizes are larger than the scan diameter. OCT is an optical imaging technique. A near-infrared light beam is sent through a rotating fibre and a prism to the vessel wall. The intensity of back-reflected light is used to measure the thickness of tissue layers. Therefore the blood vessel has to be flushed with a transparent liquid during image acquisition. To create 3D Volume scans, the fibre is pulled back while rotating creating spiral image data. A combination of OCT and white light endoscopy could have the potential to visualize defects in the vessel wall and in parallel in one pull back on the vessel wall surface. The aim of this paper is to create a first feasibility study of a combination of WLI, NBI and OCT. Therefore, a test setup is designed and experiments were performed using artificial and tissue phantoms.

2 Methods

2.1 Creation of a test setup

A structured development process was applied for conceptual design of the test setup [10]. A requirements analysis was performed to define the test parameters according to the anatomic structure of interest. In parallel a schematic draft of

a possible setup was created to identify all necessary parts involved (Figure 2, 3).

A mobile endoscope camera system and a lighting system [11] for image acquisition was selected to be connected to the proximal end of an optical fibre endoscope. The fibre endoscope was evaluated in a prior study [12]. For our test an endoscope with 0.75 mm diameter and 6000 pixels (MICRO-EPSILON Eltrotec) was used. A micro catheter was used to house the optical fibre endoscope. The micro catheter and the OCT catheter are introduced into the vessel through a flushing or guide catheter. They are placed in such a way, that their field of view overlap each other. Flushing is necessary for OCT and optical imaging and could be done through the guide catheter. The micro catheter should have a permanent low flow flushing in order to prevent the blood from clogging on to the lens of the optical fibre. The OCT measures the echo time delay and the signal intensity after its reflection or back-scattering from the wall structures while simultaneously operating a pull-back along the artery. Thus, cross sections of the artery are obtained. The OCT catheter has a pull-back distance of about 54mm in about three seconds. For employing the optical fibre with the OCT, it is necessary to pull-back the fibre at the same speed. So, a pull-back device has to be built to facilitate the motion of the optical fibre and also to synchronize the movement with the pull-back of the OCT catheter.

A stepper motor (Polulu nema 17) is used to provide controllable rotational motion. To convert into translational motion, a threaded bar with a nut is connected to the motor as a linear drive. In order to control the motor a driver DRV 8825 was used. For the programming and controlling part a microcontroller (Arduino 3 board) was utilized. The motor

Figure 2: Schematic setup of a combined WLI/OCT system

Figure 3: Detail of catheter placement and imaging area

Figure 4: Control unit for the pull-back device

Figure 5: Pull back for movement of the optical fibre endoscope

control setup is shown in Figure 4, Figure 5 depicts the complete pull back system.

2.1 Measurements

For the experiments, the complete assembled pull back system with endoscopy was incorporated with an OCT system (Ilumien, St.Jude Medical) (Figure 6). The OCT catheter (Dragonfly, St.Jude Medical) was inserted into the guide catheter using a valve. A thin guide wire was inserted into the rapid exchange lumen of the Dragonfly catheter to keep the catheter on track. The OCT catheter and the micro catheter were placed in such a way, that the end of the micro catheter is in line with the lens of the OCT catheter.

Figure 6: Test setup for combined WLI/OCT imaging

In a first test, the combined imaging was evaluated on artificial test samples. We used syringes with a distinct pattern on the inner side and a wire structure on the outside (Figure 7a+b) [12]. That allows visibility in optical endoscopy and OCT. The syringes have a length of 54mm and diameter of 5mm and are filled with water. The syringes were separately fixed on to a piece of aluminium profile for acquisition.

In the second step, a porcine vascular sample was used for acquiring images. The tissue sample was put into a syringe

Figure 7: Syringe pattern phantoms (a, b) and vascular test sample (c) used for imaging

tube in order to stretch the walls for better visualization (Figure 7c).

While imaging the phantoms and the tissue the focus was set outside before entering the phantoms. In all the acquisitions the starting points of the catheters were on the distal end outside the tissue or phantom. By pulling back the fibre endoscope while activating the OCT acquisition, simultaneously images were acquired in the OCT system and the endoscopy system in 4K resolution. Phantom images were acquired using normal pull-back speed which was roughly 18mm/s. In the tissue sample, images were acquired with normal pull-back speed and slower pull-back. The pullback speed was adjusted by changing the delay in the arduino code. The delay was doubled to achieve a reduced pull-back speed of around 9mm/s.

3 Results

Several image sets of the syringe phantoms were acquired. The images obtained using the fibre endoscope and the OCT were analysed subjectively. The OCT images were of good quality. The fibre endoscopic images were of low image quality. Potential causes for the foggy appearance in the fibre images includes the loss of focus point of the camera system, the low resolution of the fibre endoscope, and the fast pull-back of the catheter. As the video acquisition started outside the syringe, the focus was set at a longer distance. When the acquisition began, the focus couldn't adapt quickly enough resulting in blurry appearance. Repeating the test with focussing inside the phantom improved the image quality. The line patterns on the side wall of the syringes and the end wall were now clearly visible. The presence of the end wall also helped to focus easily at a shorter distance rather than having an open end.

Figure 8: Images of the line pattern syringe phantom, left: WLI image, right OCT image

The vascular tissue sample was imaged with normal and slow pull back speed. Several acquisition parameters of the camera were evaluated. An example image acquired from the vascular

Figure 9: Images of the vascular tissue phantom, left: WLI image, right OCT image

sample using normal pull-back is shown in Figure 9. A bifurcation is clearly visible on the right down side of the central lumen in OCT and WLI. The quality of the WLI was good in this case. Here autofocus of the camera worked better than in the first phantom tests as the acquisition began inside the tissue. The vasculature appears whitely without presence of real blood circulation. For this reason, additional NBI was not used in this test since NBI is most effective with haemoglobin inside the structures.

4 Conclusion

The entire study aimed to check the feasibility of a bimodal system by combining the OCT system and fibre endoscopic optical imaging system, whereby two kinds of images of the same structure are obtained simultaneously. Identification, sorting and selection of the components were done systematically. Selection of the fibre involved a comparative study of the available fibres. Even though the fibre endoscopic images were not good as expected, the combined system was proved to be feasible. The potential issues are focusing of the camera, blurring because of the flushing liquid and the resolution of the fibre endoscope. Further studies have to be done to address the identified issues. The approach seems to be promising and even though the technical feasibility is shown, it needs further experiments and a more professional acquisition setup to develop a realistic system suitable for a clinical use.

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