Axel Boese*, Christoph Arens and Michael Friebe

Novel flexible endoscope concept with swiveling camera tip

A new approach for endoscopic inspection of narrow anatomical structures

Abstract: Endoscopy is an important modality in medical imaging. Thin flexible endoscopes are for example used to examine the upper airways, for gastroscopy procedures or lung inspection. With standard flexible endoscopes one can change the direction of view by bending the tip with the disadvantage of large space required due to the bending radius. With first experiences of a concept of a moveable camera head on the tip of rigid endoscopes, we now propose a novel design employing a swiveling camera for flexible endoscopes. This concept is based on the use of a shape memory wire used to control the movement of the camera, a flexible plastic flap joint for tight rotation and flexible printed circuits for the electronic connection. The prototype was realized in a first low cost setup using a 5,5 mm HD chip on the tip camera with LED light. The motion and imaging performance of the prototype allowed swiveling of the camera on the endoscope tip from straight view to 100° side view. The space needed in fully rotation was limited to 9mm with an overall diameter of the endoscope in straight view of only 5,6mm, but could even be further reduced in a more professional setup. The image quality is good, but close-up views appear blurry due to the fixed focus point of the low-cost camera. The presented steering concept of the camera is promising, as it could potentially improve imaging of narrow cavities using flexible endoscopes. Especially for "in office" examinations this principle could add value to diagnosis and patient comfort.

Keywords: flexible endoscopy, bending radius, shape memory, chip on the tip, steering

https://doi.org/10.1515/cdbme-2020-3073

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1 Introduction

Endoscopy is one of the most important imaging modalities to visualize internal structures inside the human body. It is used for diagnosis as well as for observation of treatment procedures in various clinical applications. There are several types of endoscopes available. It can be distinguished between rigid endoscopes, mainly build out of lens stacks, and flexible ones. All endoscopes in medical application allow the connection to a light source to illuminate the field of view [1]. Flexible endoscopes can be made out of glass fibres as visual channel, especially for thin diameters. These endoscopes can be combined with a camera on the proximal end. But more and more flexible endoscopes use small cameras directly on the tip (chip on the tip). Flexible endoscopes are mostly equipped with a steering mechanism to bend the distal end like a finger. This allows directing the endoscope to facilitate placement and additionally to change the direction of view during inspection. Due to the used technology for steering based on pull wires and an outer tubular strutting, the achievable bending radius is big, approximately 10 times of the endoscope diameter. Space is needed for the bending itself and the distance to the region of interest can be reduced, hindering the camera to focus. This leads to limited performance in narrow cavities or tubular structures (see **Figure 1**).

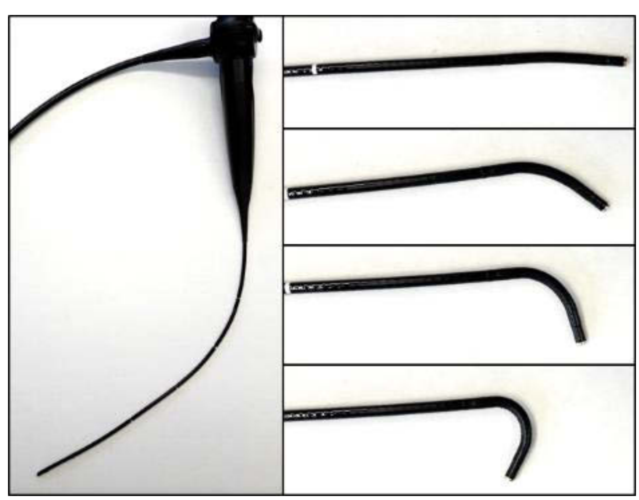

Figure 1: Standard (4mm) flexible endoscope with bended tip

In [2] a rigid endoscope was described, that allows the change of direction of view by a swiveling camera on the tip. The camera is mounted on a ball that is rotatable and activated by a motorised Bowden cable. Thus, it can be swept from a straight view to 120 degrees without leaving the endoscope axis. This principle was developed to support laryngeal surgeries in combination with an endoscope manipulator system [3]. But the clinical use of rigid straight endoscopes is limited by the accessible anatomy or would not be tolerated by the patient without general anaesthesia.

To improve the options for endoscopic diagnostics and to transfer the principle of a swiveling camera on the endoscope tip into flexible applications, a new design was developed. We present this first prototype mechanism based on a shape memory wire, a flexible plastic flap joint for steering and flexible printed circuits for electronic connection.

2 Methods and Materials

2.1 Observation and requirements analysis

For design of a system that meets the need of the clinical application, a user integrated approach based on [4] was performed. Therefore, the use of rigid endoscopes in diagnostics and surgeries at the larynx and the use of flexible endoscopes for diagnostics of the upper airway were observed. The handling of the system including insertion, rotation, manipulation of the tip, guidance through the cavities and cleaning after contact with the wall or fogging were analysed. The system diameters, interaction with other devices and anatomic dimensions were documented. This input serves as basis for the requirements for the new flexible endoscope with swiveling camera tip.

2.2 General concept

To develop the new endoscope three major sub functionalities were identified:

- imaging including camera, light and power transmission
- manipulation of view including steering and flexible transfer mechanism
- controlling of imaging, light and motion.

Imaging can be realised by a “chip on the tip” camera module including light. For realisation of a swiveling mechanism on the tip of a flexible endoscope, a mechanism has to be developed that allows precise control of the camera motion without influencing the stiffness of the overall system. For this reason, the common technology of a pull wire for steering was substituted by a push wire. Thus, the compression of the system is turned into a stretching that reduces deformation of a nonlinear placed endoscope. A shape memory alloy wire, Nickel Titanium (NITINOL), was selected for propagation of the movement from the handle at the proximal end to the tip. This wire allows force transmission while keeping the tip flexible and is resistant to kinking. The push wire has to be guided by a tight tube like a Bowden cable to avoid evasive movement. The flat camera chip is loosely connected to a plastic flap on one side to the wall of the outer protective tube. The push wire is connected to the other side of the chip. By pushing the wire, the camera chip is rotated around the connection point on the outer tube that acts like a joint.

To seal the system but keeping the movability, a hood made out of flexible, deformable material should be used for the distal end of the endoscope. A sketch of this concept is shown in **Figure 2**.

A handle is needed to realize steering of the endoscope and the camera tip with one hand while the other hand is used for feeding the endoscope in.

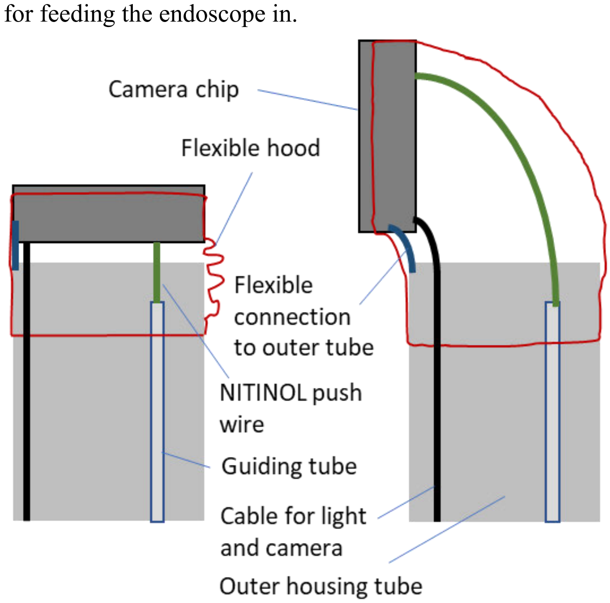

Figure 2: Sketch of the concept for a swiveling camera on the endoscope tip, left: straight view; right: view 90 ° to the left side

2.3 Prototype realisation

Based on the general concept, the parts for realisation of a first prototype were selected. For imaging including illumination a 5.5mm HD USB camera module (UEETEK IP67 5,5mm) was selected. It can be easily connected to computers or smartphone for image acquisition via USB. For the prototype the camera has to be adapted. To achieve flexibility, the housing was opened and partwise removed. The chip of the camera has to be uncoupled from the main board while keeping the electric connections. Therefore, a flexible printed circuit is used.

For the transmission of the movement from the proximal end to the distal tip a 0,5mm NITINOL wire was used in combination with a 0,8mm cable protection tube as guide. Together with the connecting cables for light and camera, the transmission wire and guide are fed into an outer 5,6 mm protection tube. One side of the camera is glued to a small flap on the distal end of the outer protection tube to create the joint. The distal end of the NITINOL wire is glued to the bottom of the camera on the opposite side of the joint. By pushing the wire, the camera swivels around the rotation joint up to 100 degrees. The NITINOL wire allows small bending radius without kinking.

Finally, the whole endoscope tip was covered with a highly flexible hood which was glued around the protection tube on one end and the lens cover of the camera on the other side. This hood acts like a rubber gaiter creating folds when the view is straight and being stretched when view is swivelled to the side. The adaption of the camera and assembly of the endoscope tip is shown in **Figure** .

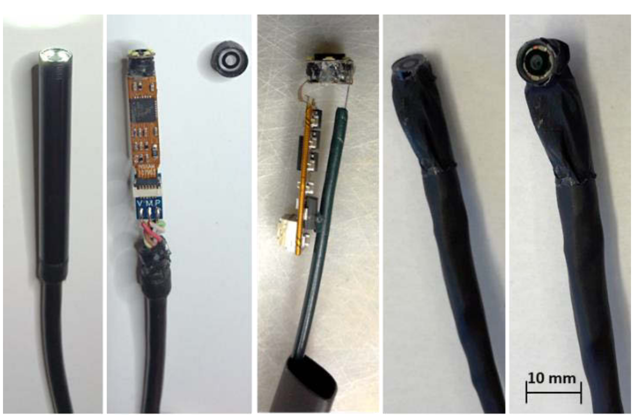

Figure 3: Adaption and assembly of the camera head

To manipulate the camera motion and for appropriate handling, a handle was design made out of two half shells. Shape and usability concept were adapted from state-of-the-art endoscopes on the market. Inside the handle the electric cables and the transmission wire are separated into two channels. The camera and light cable with USB plug was only guided through the grip. The guiding tube for the transmission wire was fixed inside one half shell as counter mount for the swiveling mechanism. The NITINOL wire was connected to a rotatable lever that allows nearly linear feeding into the guiding tube. The handle was realized by 3D printing (Prusa FDM Printer, Czech Republic).

2.4 Testing

During testing of the endoscope, the range of movement of the camera and the required space around the tip therefor were evaluated (see **Figure 4**). Additionally, the reaction of the flexible shaft of the horizontal free hanging endoscope was observed when manipulating the camera.

This is relevant to estimate possible interactions with anatomical structures.

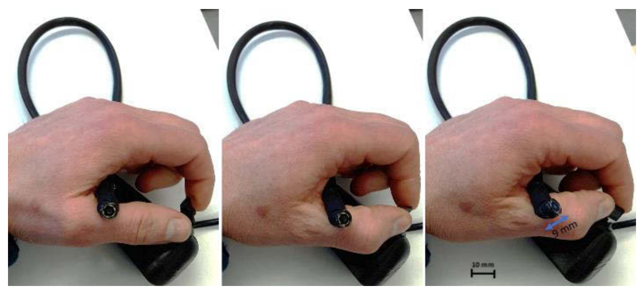

Figure 4: Swiveling the camera from straight view to 100° view by one hand control

Finally, the endoscope was fed into a hollow hand simulating a narrow anatomic structure and secondary tested under water to proof sealing. Video sequences and images were acquired while placement and while swiveling the camera. Usability of the endoscope and the handling concept were analysed in parallel.

3 Results

A prototype of a flexible endoscope with a swiveling camera was realized. The endoscope has an outer shaft diameter of 5,6mm and a length of 300mm. A HD camera, that can swing around a flexible fixation point from 0° straight view to 100° side view is mounted on the tip. For a full camera motion, a circular space of only 9mm is needed. The test of the shaft reaction showed a stretching of less than 1mm in all orientations of the endoscope. Imaging was tested on the hollow hand model. Image quality and illumination was excellent in straight view with a distance of 15 mm to the object. When swiveling the camera to the side, the distance to the object reduces to less than 5mm. This leads to blurry image due to focusing issues (**Figure 5**).

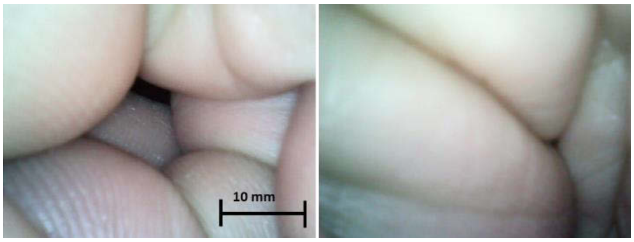

Figure 5: Test of imaging with a hollow hand model, close ups appear blurry (right)

Testing under water showed now leakage or effects on the electronics. This was evaluated after assembly and after more than 100 motion cycles.

After 15 minutes of use with full power illumination, the camera head showed an increase of temperature to 43 ° generated by the 6 LEDs.

The handling of the endoscope and control of the swiveling mode was intuitive and comparable to standard endoscopes on the market.

4 Discussions and Conclusion

The concept of a thin flexible endoscope with a swiveling camera could be realised. For this prototype we only used low cost parts and manual manufacturing and assembly. Even with these preconditions a demonstrative result was possible. The swiveling mechanism acts reliable and intuitive with smallest space requirements. Kinking of the transmission wire was not observed even when the endoscope was deformed into two 50mm loops. To achieve better image quality in close up situations the range of focus has to be adapted. By substitution of the LED light by light fibres in combination with a scattering element, the heat development can be avoided and the diameter can be reduced further. The design offers the possibility to add another steerable element, for example 30 mm before the distal tip, to enable additional control or fixation while placement or in larger cavities.

A thin, flexible endoscope with a swiveling camera offers more opportunities for diagnostics of narrow anatomical structures. Since flexible endoscopy is better tolerated by patients this type of endoscope can be used for imaging structures that are hard to reach even in "in office" application.

Author Statement

Research funding: The author state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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