A Virtual Endoscopy System for the Planning of Endoscopic Interventions in the Ventricular System inside of the Human Brain

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ABSTRACT

Virtual Medicine is an emerging and challenging field in Computer Graphics. Numerous visualization methods are used to model and render data of different modalities. In recent years, Virtual Endoscopy has become a very popular area in Virtual Medicine. Different approaches address various applications like colonoscopy, bronchoscopy, or angiography. In this paper, we present an endoscopy system for Virtual Endoscopy of the ventricular system inside the human brain. The main purpose of this system is to provide support for the planning of complicated endoscopic interventions inside of the ventricular system.

Keywords: Virtual Reality, Virtual Endoscopy, Ventriculoscopy.

1. INTRODUCTION

Minimally-invasive neurosurgical procedures are of increasing importance in neurosurgery. In comparison to commonly used surgical techniques, less healthy brain tissue is damaged. Furthermore, minimally-invasive procedures have less deleterious effects on the patient. On the other hand, these procedures lack fast access in the case of serious complications, such as strong bleeding. Therefore, careful planning and realization of this procedure is essential, in order to avoid such complications. This problem is increased, because handling and control of these endoscopes is very difficult, mainly due to limited flexibility of and limited field of view through the endoscope, and the sensitive nature of the brain tissue [1].

To optimize the success of these interventions, an improved planning and training environment is required. Traditional planning of endoscopic interventions in neurosurgery is based on the thorough examination of slice images of a MRI scan. In cooperation with the Department of Neuroradiology and the Department of Neurosurgery of the University Hospital at Tübingen, we developed a virtual ventricle endoscopy system, which adds an additional step by using Virtual Endoscopy methods for examination and planning. In our approach, this step consists of two stages; a preprocessing stage and the actual Virtual Endoscopy of the ventricular system (Figure 1).

The remaining parts of this paper are organized as follows. We continue with a brief overview of the field of Virtual Medicine, with a special focus on Virtual Endoscopy applications. Section 3 briefly outlines the medical and anatomical background. In Section 4, we present technical details of our virtual endoscopy system, which is applied to Virtual Ventriculoscopy in Section 5. Finally, we conclude and discuss future directions of research.

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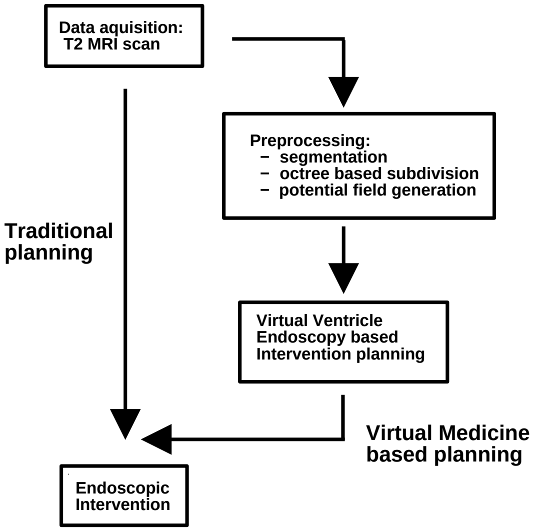


Figure 1. Flow of Virtual Endoscopy-based intervention planning.

2. RELATED WORK

There has been quite some work in the field of Virtual Medicine. In this Section, we present a brief discussion of some of the related work. Among the first is Ref. [2], where methods of Computer-Aided Geometric Design (CAGD) were applied for planning of cranial surgery.

In Ref. [3–5], Finite Element Methods were used to construct models of tissue of the human body. These models were used to simulate deformations of the tissue to predict the outcome of plastic or craniofacial surgery. Computer-based anatomical atlases were introduced by Höhne et al. [6]. Based on CT and MRI volume data, methods of artificial intelligence and volume rendering were combined. Recently, Serra et al. introduced a framework for stereo-tactic frame surgery [7], using a set of computer-based tools and a 3D-output device, similar to the virtual table paradigm.

One of the major recent research topics in Virtual Medicine is Virtual Endoscopy. Frequently, the proposed methods generate off-line animations of virtual cameras simulating an endoscopic session through various hollow organs. In 1994, Geiger and Kikinis proposed using Finite Element Methods to specify a path of the camera [8]. Similar approaches of automatic generation of the camera path were investigated by Vining et al.[9], Lorensen et al. [10], and Hong et al. [11]. In contrast, Rubin et al. manually specify a key-frame interpolated camera path [12]. General Electric Medical Systems (GE) developed the Navigator, which exploits a ray casting approach to generate the view through a virtual endoscope. The user can freely navigate through the 3D dataset [13–17].

Hong et al. proposed a new navigation method, implementing the guided-navigation paradigms [18]. By combining distance fields and kinematic rules, an intuitive scheme for navigating inside the human colon was developed. Furthermore, a customized visibility algorithm was proposed in order to reduce the number of surface polygons of the inner surface of the colon to a feasible size. While this system provided a fast and intuitive handling of the virtual endoscope, it required high-end SGI InfiniteReality graphics for interactive framerates.

Meanwhile, Virtual Endoscopy procedures were applied to a variety of medical applications. Most notably, it was applied to colonoscopy [18,9], to bronchoscopy [16,14], and endoscopic examinations of blood vessels [15,19]. In 1998, Auer and Auer [13] used the GE Navigator to apply Virtual Endoscopy methods to ventriculoscopy, the endoscopic examination of the ventricular system of the human head.

3. MEDICAL BACKGROUND

In minimally-invasive neurosurgery of the brain, existing cavities can be used as a preformed path for movements of the endoscope, without destruction of brain tissue. Our focus is on the ventricular system of the human brain, in which the brain liquor (cerebrospinal fluid or CSF) is produced and resorbed. To access the ventricles, a hole is drilled through the skull and a tube is placed through this hole into the ventricular system. Thereafter, the endoscope is introduced through the tube, which is used as a stable guide for the endoscope.

Because of the water-like optical property of the CSF - which fills the ventricular system, viewing of the surrounding tissue is possible. Movement of the endoscope - guided by video-control via the small field of view of the endoscope - is limited by the tube and the surrounding tissue. Micro-instruments, introduced through an additional canal inside the endoscope, can then be used to perform the actual minimally-invasive procedure, e.g. removing accessible mass lesions.

Due to respiration and other metabolistic activity, the CSF flows through the cavities inside the human brain. In some cases, the connection between the third and fourth ventricle - the aqueduct - is blocked by occlusion or stenosis. This causes a serious disturbance of the natural flow of the CSF, which frequently leads to a dangerous increase of pressure inside the skull and can damage the brain severely. The clinical picture of this hydrocephalus is one of the major indications for a minimally-invasive intervention in the ventricular system, where a bypass is realized by perforating the floor of the third ventricle. However, the limited view and orientation through-out the intervention increases the necessary time of the intervention and consequently, the inherent risks of serious complications. To overcome these drawbacks, we propose the use of a virtual endoscopy system to improve the planning of and orientation during this procedure.

4. VIRTUAL ENDOSCOPY SYSTEM

Following Hong et al.[18], we adopted the guided-navigation paradigm in order to provide additional orientation to the users. This paradigms provides the user with some orientation guidance while ensuring full interactivity and user control. The rendered scene is a polygonal representation of an extracted isosurface depicting the inner surface of the ventricular system. These reconstructions usually result in a large number of polygons to be rendered. To reduce this number, a visibility culling scheme is applied.

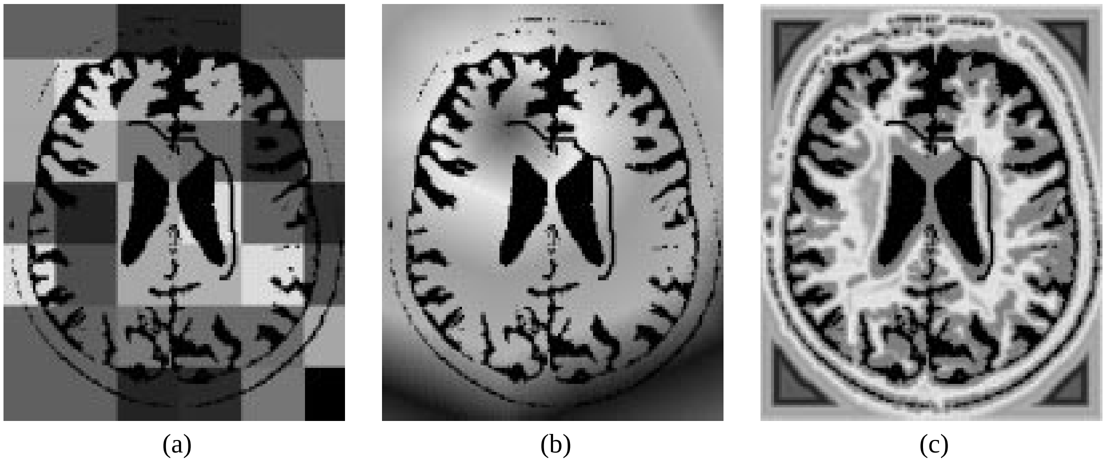

(a) (b) (c)

Figure 2. Preprocessing example on a non-segmented dataset. The black line is the projection of the default path of the virtual endoscope. (a) Octree decomposition of the image stack, (b) Potential field coding the drift to the target point, (c) Potential field coding the distance to the inner surface of the ventricles.

4.1. Preprocessing

The basis of our preprocessing is a T2-weight MRI scan of the head, acquired using a CISS sequence, where we are especially interested in a good contrast for the ventricular system. After segmenting the inside of the ventricular cavities using a 3D region growing algorithm [20], we generate the default path of the virtual endoscope. This path is necessary for the guided-navigation; the virtual endoscope moves along this path if no user-interaction is used.

The second preprocessing step uses an octree decomposition to generate a spatial subdivision of the volumetric representation of the image stack (see Fig. 4). Only segmented parts of the ventricular systems are considered for this decomposition

[21]. Based on the generated subdivision, the isosurface representing the inner surface of the ventricles is extracted using the Marching Cubes algorithm [22].

Finally, three potential fields are generated in order to provide the drift along the default path to the target point at the end of the path (see Fig. 4), or to the seed point at the start of the path. Furthermore, a potential field coding the distance to the inner surface of the ventricles is generated (see Fig. 4). The latter potential field is used to implement a collision avoidance functionality; the closer the virtual endoscope approaches the inner surface, the larger the calculated repulsion draws back the virtual camera.

4.2. Interactive Virtual Endoscopy

4.2.1. Visibility-based Rendering

After the preprocessing stage, the virtual endoscopic examination is performed. Usually, the polygonal representation of the ventricular system consists of approximately half a million triangles. Rendering this polygon load in realtime (approx. 20 fps) far exceeds the performance of mid-range state-of-the-art graphics workstations. Consequently, we are using a visibility-based rendering approach, in order to reduce the actual number of polygons to be rendered. Based on the generated octree-decomposition of the image stack, each subdivision entity is tested if it is located within the field-of-view (FOV). Only entities which lie at least partially inside of the FOV can be visible. Therefore, only these are considered for rendering [23].

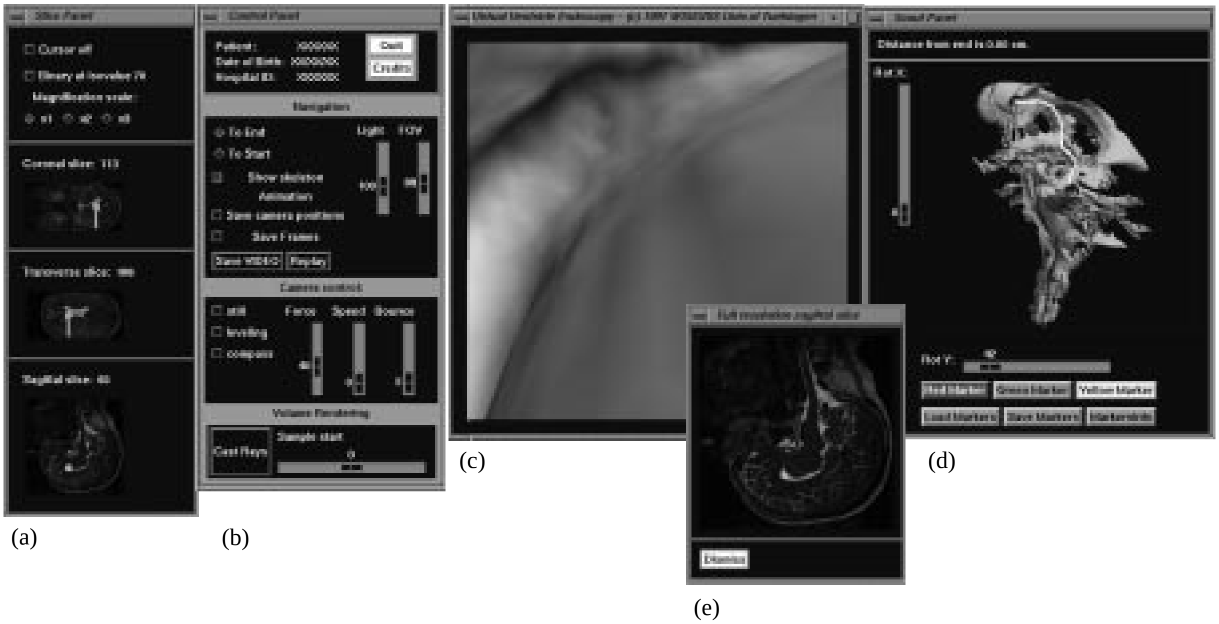


Figure 3. User-Interface of the virtual ventriculoscopy system: (a) Slice Panel, (b) Control Panel, (c) Main View, (d) Scout Panel, and (e) Full Resolution Sagittal Slice Panel.

Using this visibility-based rendering approach, we achieve rendering performance of several frames on low-end graphics workstations such as a SGI O_2. However, this render performance is not really interactive and needs further improvement. Applying more advanced occlusion culling algorithms is necessary [24]. Last year, Hewlett-Packard released its fx-series of graphics workstations [25]. These graphics systems provide hardware-support for fast occlusion culling. Running the Virtual Endoscopy software on a fx4 graphics workstation achieved a framerate of more than 12 frames per second, a rate which is considered as interactive.

4.2.2. User-Interface

The user-interface consists of four components; the main endoscopic view, the slice panel, the scout panel, and the control panel. The main endoscopic view (see Fig. 3 (a)) provides the view through the virtual endoscope and some user-interaction, such as measurements and navigation. Additionally to the main endoscopic view, the system provides the sagittal, transverse, and coronal cross sections of the image stack (see Fig. 3 (a,e)). The scout panel provides a fully rotatable external view on the three-dimensional reconstruction of the ventricular system (see Fig. 3 (d). Furthermore, this panel includes the setting and management of markers, which can be used as orientation points. The final component - the control panel - controls the general system parameters, navigation, video generation, and volume rendering (see Fig. 3 (b)).

5. VIRTUAL VENTRICLE ENDOSCOPY

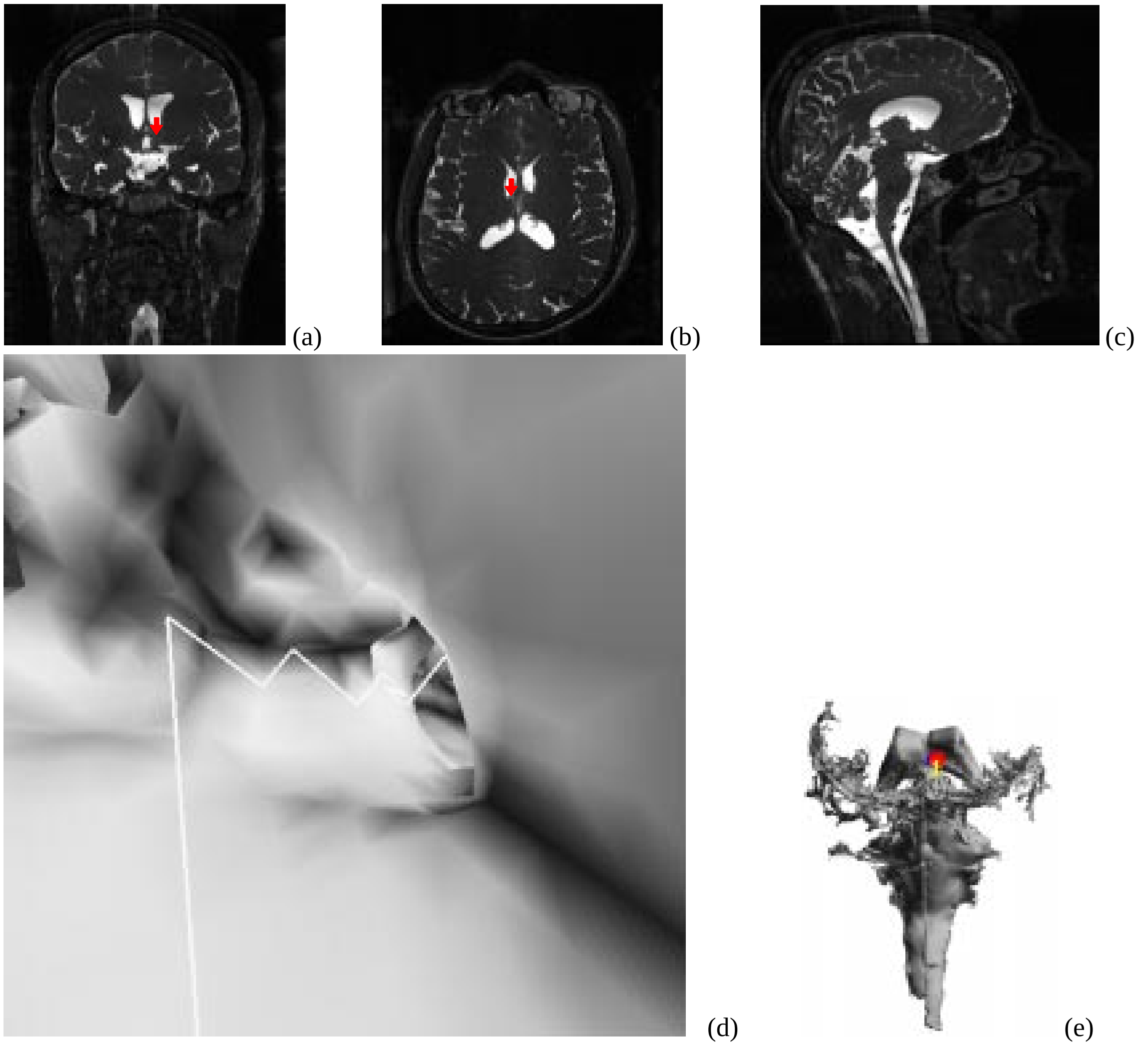
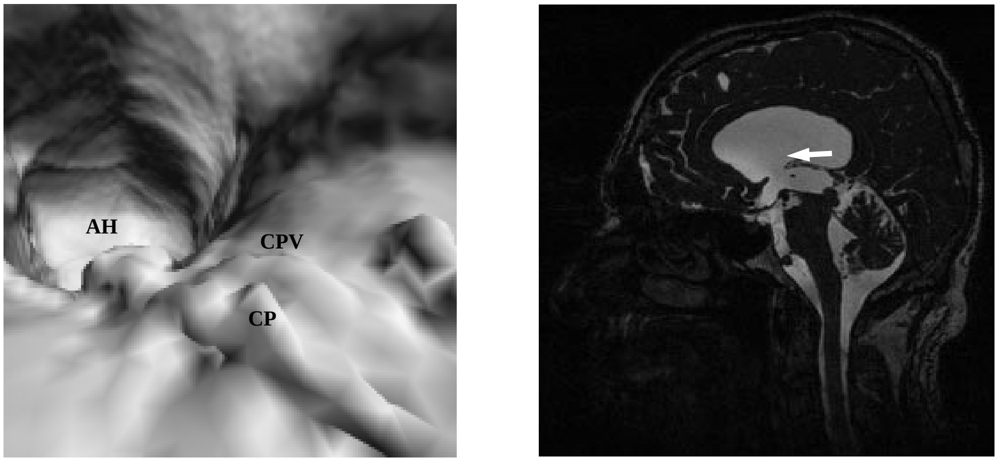


Figure 4. Snapshot from Virtual Ventriculoscopy of dataset A: Normal Left Lateral Ventricle. View from the Anterior Horn through the Foramen of Monro into Third Ventricle. The arrows indicates the view direction. (a) Coronal section, (b) sagittal section, (c) transverse section, (d) endoscopic view, and (e) 3D reconstructed ventricular system.

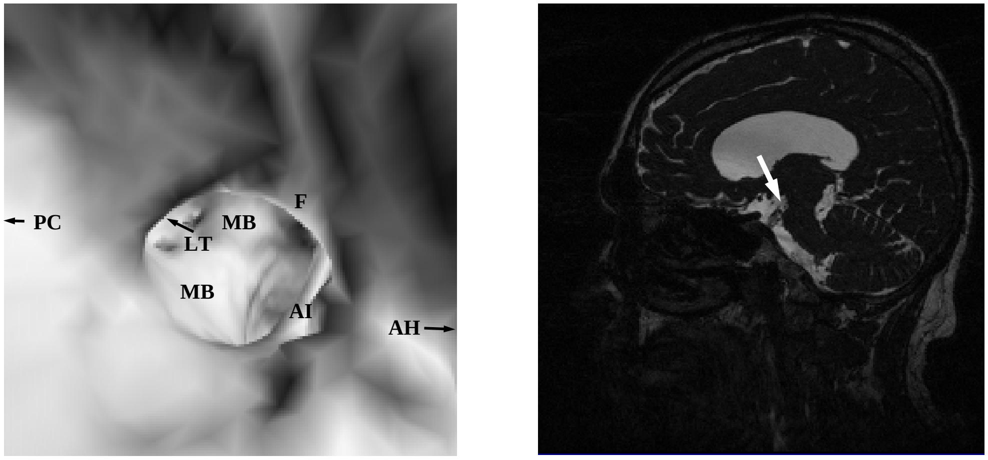
In this Section, we show examples of the Virtual Endoscopy of the ventricular system based on T2-weight MRI scans, acquired using a CISS sequence. Different areas of the ventricular systems are examined. This includes Lateral Ventricles, Third and Fourth Ventricle, Foramen of Monro, and Cisterna Magna. In Figures 5-8, we denote left with L and right with R. From the available views, we selected the endoscopic view on the left, and the sagittal section on the right.

Figure 4 shows an overview of the generated images of the Virtual Endoscopy System. The used MRI scan is of a 28 year old healthy male (dataset A). Figures 5 and 6 is based on a MRI scan of a 63 year old male patient (dataset B). The first row of images show the dilated Lateral Ventricles. The final dataset is based on a MRI scan of another patient (dataset C; details were not available at press deadline) (Figures 7 and 8). Most of the areas of interest are comparable to the respective areas of the second dataset.

The examined datasets showed most of the anatomical structures in good detail. However, some of the structures are difficult to determine, due to the lack of texture information which is available through the optical endoscope. Furthermore, due to partial volume effects, thin structures - i.e., Lamina Terminalis of Third Ventricle - were not always detected by the MRI scan. This led to a connection between the Third Ventricle and the CSF-filled cavities behind the Lamina Terminalis.



Left Lateral Ventricle, approach from Posterior Horn via Pars Centralis (PC) to Anterior Horn (AH): CP = Choroid Plexus, CPV = Choroid Plexus Vein.



Foramen of Monro, approach via Right Lateral Ventricle: PC = Pars Centralis, AH = Anterior Horn, F = Fornix, AI = Adhesio Interthalamica, MB = Mamillary Bodies, LT = Lamina Terminalis.

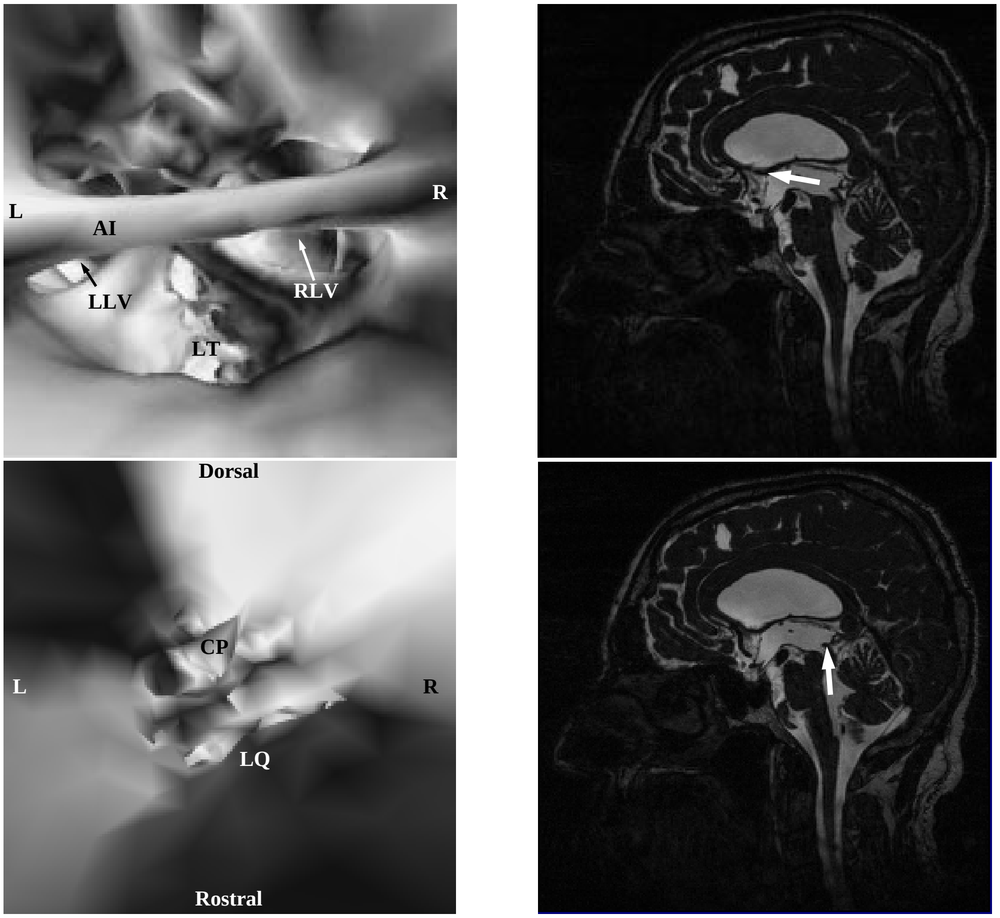
Figure 5. Snapshot from Virtual Ventriculoscopy of dataset B.

6. CONCLUSION AND FUTURE WORK

In this paper, we presented a virtual endoscopy system for the planning of endoscopic interventions inside the ventricular system of the human brain. In order to provide an intuitive handling of the virtual endoscope, we applied a guided navigation system as proposed by Hong et al. [18]. Furthermore, a visibility-based rendering scheme is applied to provide interactive performance on mid-range graphics-workstations.

So far, we used this system to examine approximately five MRI scans. Although we have found encouraging results with our preliminary examinations, we encountered some problems as well. Most of these challenges were segmentation problems due to partial volume effects. Furthermore, three-dimensional orientation within the ventricular system is still difficult. Solutions to these problems are on the agenda for future research and developments.

Currently, the virtual ventriculoscopy system is in an experimental stage. Consequently, the thorough clinical evaluation of the usability of this system is another important future research focus. This is especially important if the virtual endoscopy



Foramen of Monro, approach from Third Ventricle: LLV = entrance to Left Lateral Ventricle, RLV = entrance to Right Lateral Ventricle, AI = Adhesio Interthalamica, LT = Lamina Terminalis

Aqueduct, approach from Fourth Ventricle: CP = Choroid Plexus, LQ = Lamina Quadrigemina.

Figure 6. Snapshot from Virtual Ventriculoscopy of dataset B.

system is used as a navigation aid during the endoscopic intervention. Last but not least, our system is not limited to this single application. In the future, we will look into other application of virtual endoscopy.

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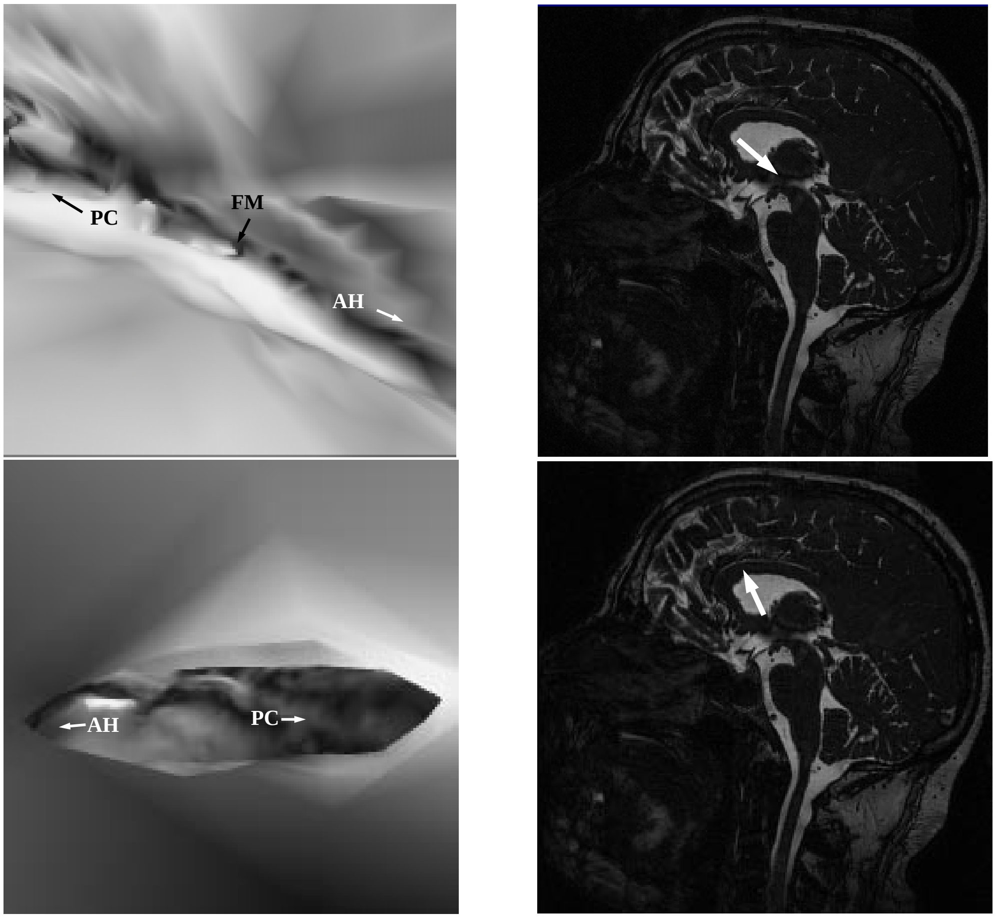

Foramen of Monro (FM), approach from the Left Lateral Ventricle: PC = Pars Centralis, AH = Anterior Horn.

Foramen of Monro, approach from Third Ventricle - View through Foramen of Monro into Lateral Ventricle: PC = Pars Centralis, AH = Anterior Horn

Figure 7. Snapshot from Virtual Ventriculoscopy of dataset C.

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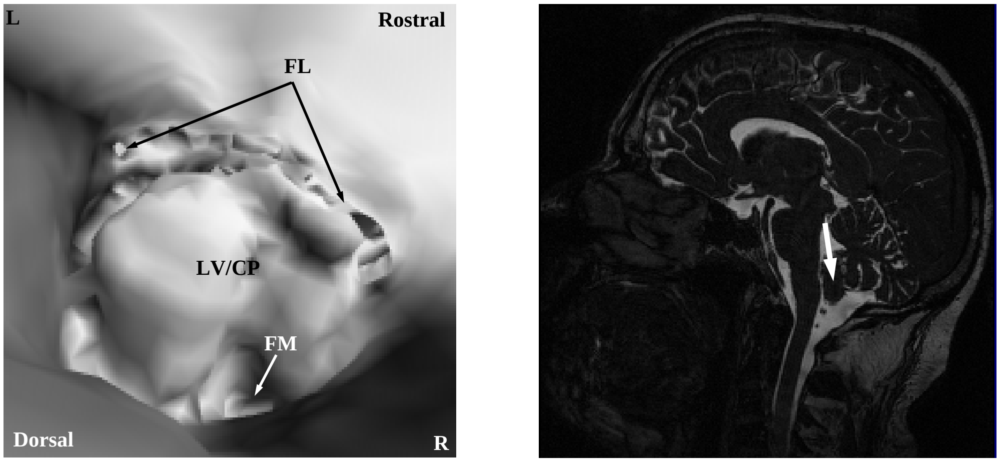
Floor of Fourth Ventricle: LV = Lower Vermis, CP = Choroid Plexus, FL = Foramen Luschkae, FM = Foramen Magendii



Cisterna Magna: PICA = Posterior Inferior Cerebellar Artery, MO = Medulla Oblongata.

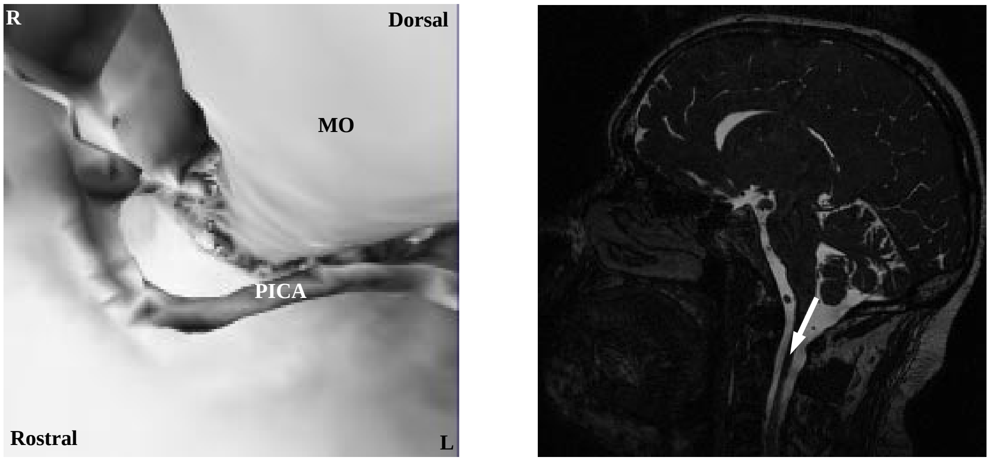


Figure 8. Snapshot from Virtual Ventriculoscopy of dataset C.

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