Virtual dacryocystorhinostoscopy in intraoperative navigation in the hybrid technology of endonasal endoscopic dacryocystorhinostomy

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Aims and objectives

The advantages of endoscopic diagnostics include low invasiveness, vast possibilities of surgical correction (including laser methods of surgical intervention) using extremely small approaches, as well as great possibilities to adjust magnification, view and optic axis angles deviation, etc. Modern endoscopic systems are combined with digital video capture systems and allow for obtaining high resolution images providing a significant part of information about the surgical anatomy in the operation zone.

Drawbacks of this method include the necessity of additional training of the surgeon associated in particular with the fact that endoscopic image is not only two-dimension, but also subject to magnification-related aberrations and consequently to fish-eye phenomenon.

First suggested by Vining et al. in 1994, VE (9, 10) is an instrument for postprocessing of primary isotropic images obtained from diagnostic modalities, first of all, computer and magnetic resonance tomography. This method allows for creating a virtual 3-dimension surrounding through forming surfaces of media borders on the basis of Hounsfield units difference. Within the 3D environment obtained in this way it is also possible to obtain movement of the point, angle, visual axis direction and rotation of the observer’s visual field. These capacities of VE were formerly widely used in medicine, particularly in otorhinolaryngology (5), neurosurgery (7), including planning of trans-sphenoidal approach for pituitary surgery, as well as for planning of microinvasive operations (5) and endoscopic operations (11).

The purpose of this study is to estimate the practical applicability of endonasal VE as an intraoperative navigation instrument during endoscopic endonasal interventions on lacrimal passages.
Methods and materials

Data obtaining

Standard computer tomography protocol was used before endonasal dacryocystorhinostomy in 96 adult patients with clinically confirmed dacryocystitis (192 orbits and lacrimal sacs). Computer tomography was performed with various multispiral tomographs: from 16-row to 64-row. Investigations were performed in helical scan mode with 16 to 64 active detector lines, with short focus (<240 mm), 120 kV, 250 mA, pitch 0.41, with tube rotation time of 0.5 - 0.6 sec, and reconstruction slice thickness of 0.5 to 0.625 mm. An individual effective dose amounted to 1.7 mSv to 2.1 mSv. Reconstruction was performed with 0.5 mm step and formation of two volumes different by convolution kernel value - in Bone Standard and Boost mode for bone structures analysis (corresponding to convolution kernel 75), and in Head / Brain mode for soft tissue structures analysis and for 3D reconstructions (corresponding to convolution kernel 30). Contrast enhancement was not routinely used for VE data obtaining, but optionally was applied when it was important for diagnosis of additional intra-orbital pathologic conditions.

Choice of software

First of all, the requirements to visualizing software defined by the assigned tasks were formulated:

1. Absence of additional investigations of the patient (dictated by the requirements of optimal radiation exposure and economical items);
2. Applicability of data obtained from any DICOM 3.0 compatible CT scanner.
3. Possibility of volume presentation in the form of its parts isolated automatically or semi-automatically on the basis of the attenuation data (Hounsfield unit) in each voxel or data on relative intensity of the voxel (during processing of MRI images).
4. Possibility to adjust transparency and contours sharpness, and to build colored surface for each of described segmented volume parts separately.
5. Possibility to export final video stream to wide-compatible non-proprietary video files available for playing on any video playback equipment including digital media projectors and portable electronic devices (smartphones, tablet computers, etc.).

Extended brilliance Workspace workstation (Philips, The Netherlands) was chosen as an optimal image postprocessing system meeting the above mentioned requirements.

Video data obtaining during postprocessing was formed according to the principle of needs imposed by endoscopic method:
1. **Endoscopic visual field.** Field with 90° viewing angle was used for virtual endoscopy simulation.

2. **Orientation.** Clock face navigation model (standard for endoscopic procedures) was used.

3. **Segmentation and transparency.** Segmentation was performed on the basis of attenuation level isolation tool and subsequent correction with cutoff loop. Nasal cavity walls transparency was adjusted in real time in order to achieve simultaneously both visibility of lacrimal passages models behind them and sharpness of semitransparent bone structures contours.

4. **Video registration.** Registration of video stream was performed with built-in facilities of the workstation (SnagIt pack) with minimal graphics compression and subsequent export of video data to .avi format with recording on DVD or exporting to an external USB storage device.

**Postprocessing**

Consecutive slice-by-slice isolation of contours visually corresponding to outer contours of lacrimal sacs in axial projection with W/L 340/40 HU (Soft Tissue) window parameters in reconstruction with less convolution kernel with subsequent contour correction in coronal and sagittal projections was performed using "Slice-by-Slice" tool of "Tissue segmentation" pack. Using surface building tool (Surface) 3D models of lacrimal sac and nasolacrimal ducts were obtained simultaneously and were demonstrated on isometric 3D reconstructions for visual estimation of sac location type taking into consideration the position of lacrimal sac model in relation to the front lacrimal crest. To enhance contrast of visualization, LungNodes1 filter was applied to the achieved models which gave a possibility to dye the model with high intensity regardless of its real density, preserving visualization of object surface irregularities. Then, using Endoscopy software pack, "virtual endoscopy" model was formed: standard 90° viewing angle coinciding by geometrical distortions with recorded video of optical endoscopic interventions. As an initial visualization adjustment Lung2 filter was chosen, the degree of structures transparency was set at 2, after that parameters correction of model "window" were used to achieve visualization of nasal cavity walls as transparent, preserving clearly traced borders resembling "glass walls". Switching of lacrimal sac models visualization gave a possibility to see their borders through the lateral wall.

Sequence of the examination of a 3D model of middle nasal meatus completely repeated examination protocol of optical rhinoendoscopy during endoscopic dacryocystostomy. Motion was registered with built-in SnagIt pack with High Quality adjustment of rendering quality; during optical visualization of the middle turbinate and presumed holotopic projection of the lacrimal sac on the lateral wall of the nasal cavity the transparency of nose model was changed manually from Opacity=50 to Opacity=1. Visualization of the lateral wall as "glass wall" was achieved herewith, giving a possibility to see distinctly through it the model of lacrimal sac preserving the sharp contour of the wall and the middle turbinate, which allowed "endoscopic" estimation of lacrimal sac relation to endonasal landmarks during examination of the lacrimal sac.
Captured video was recorded on a USB storage device, thus obtaining the record of a virtual 4D rhinoendoscopy with visualization of the lacrimal sac in operation field projection (Patent No. 2499581).

Practical use of the obtained data during surgical intervention

Surgical intervention was performed with the use of Karl Storz Image I Spies two-channel video endoscopic system. This system provides a possibility to watch on the monitor the images from two channels simultaneously. The first channel translated optical (real) rhinoendoscopy and manipulations in the operation field; the second channel translated on the other half of the screen a preliminarily prepared virtual endoscopy record of the same patient with lacrimal sac visualized through semitransparent or transparent walls of the nasal cavity from a connected player using DVD or USB-flash storage device. To perform optical endoscopy, rigid 3-mm rhinoendoscopes, Karl Storz shaver system and drill, Surgitron DF-S5 Ellman radio frequency unit were used. During formation of an approach to the lacrimal sac with fashioning of a muco-periosteal flap, the surgeon, looking in turn at real and virtual endoscopy, obtained additional data for exact location of the lacrimal sac. This simplified choice of location and forming of dacryocystostomy due to surgeon's confidence in location of the lacrimal sac unavailable for examination through the lateral wall of the nasal cavity which is not transparent during optical rhinoendoscopy. Lacrimal sac opening and anastomosis formation were performed via the canaliculus in an antegrade way, along the edge of the bone window using a modified Javate probe of Surgitron unit (Patent No. 2428150). After control rinsing lacrimal passage was temporarily intubated with Bika bicanalicular silicone system (FCI) with clipping tubes in the nasal cavity. Operation was finished by insertion of a biodegradable Nasopore tampon (Polyganics) to the dacryostomy zone.
**Images for this section:**

**Fig. 1:** Screenshot of a virtual rhinoendoscopy video. General view of the left \( \frac{1}{2} \) of the nasal cavity without segmentation. A view through the middle nasal meatus is presented; middle and inferior nasal turbinates, nasal septum (left in the picture), lateral wall of the nasal cavity (right in the picture) are defined.

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Fig. 2: Video stream of a virtual dacryocystorhinostomy video. General view of the left ½ of the nasal cavity with segmentation. A view through the middle nasal meatus is presented; middle and inferior nasal turbinates, nasal septum, lateral wall of the nasal cavity are defined and are still defined when toggled to semi-transparent view. Purple color marks lacrimal sac and nasolacrimal duct seen in behind lateral nasal cavity wall while it is shown as semitransparent.

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Results

Virtual endoscopy was obtained in all the investigated patients, but hybrid technology of endonasal endoscopic dacryocystorhinostomy with intraoperative navigation was implemented only in 10 cases. Complete conformity of nasal turbinates, septum, lateral nasal cavity wall images and specific features of their relief was obtained (fig.1).

Traditional radiological approach to complex radiological examination of patients with chronic dacryocystitis is aimed exclusively at exclusion of pathologies mimicking dacryocystitis and confirmation of the fact of dacryocystitis presence, in particular, on the basis of lacrimal sac dilatation (1), as well as at revealing of lacrimal passages impassability reasons (4).

In this study, besides the one mentioned above, the aim of maximal possible simplification of intraoperative navigation on the basis of the obtained virtual endoscopy method data was posed, as the priority of visual over verbal information during preoperative planning was shown before (2), and the quality of obtained visual data was sufficient to expect a good level of visual information coincidence (3).

In present study, intraoperative navigation was performed by visual matching of corresponding images, herewith the number of landmarks increased many times due to individual specific features, nameless visible elements of the relief of mucous membrane of the nasal cavity. Lacrimal passages remained clearly visible through semitransparent lateral wall of the nasal cavity in the cine of virtual endoscopy (fig. 2-4), which allowed easy imagining of their projection in optical endoscopy with considering of these additional data.

Virtual endoscopy data with segmentation and marking of lacrimal passages really provided exact and minimally invasive approach to the lacrimal sac, gave a possibility to perform dacryocystostomy in an optimal place (fig. 3-6, see comments).

Transcanalicular opening of the lacrimal sac turned to be safer than endonasal; there were no cases of damage to the posterior wall of the lacrimal sac and tarsoorbital fascia. No need of additional methods of visualization such as transillumination as well as confidence of the surgeon in location of lacrimal passages unachievable while using only transillumination data gave a possibility to shorten the operation time and, which is more important, to reduce the risk of intraoperative complications.

In general, according to world literature, success rate of endonasal endoscopic dacryocystorhinostomy varies from 79.4 to 96% (6); in particular, Trimarchi et al. showed 91.3% after initial intervention and up to 95.65% after reoperation with the time of initial operation 40 minutes and time of reoperation 35 minutes.
Iatrogenic intraoperative complications of dacryocystorhinostomy include (8):

1. Bleeding;
2. Orbital wall damage;
3. Liquorhea;
4. Canalicular damage;

It was possible to avoid all these complications due to hybrid technology, in particular, due to reliable visualization of orbital walls and nasal cavity individual anatomy along the operative approach.

Nasopore biodegradable tampon provided quicker epithelization of dacryostoma edges and did not need removal, thus simplifying postoperative rehabilitation.

So, imaging navigation made an additional contribution to simplifying endonasal endoscopic dacryocystorhinostomy and gave a possibility to reduce the number of intra- and early postoperative complications.
Fig. 3: Screenshot of a virtual endoscopy video (a) compared to a screenshot of an intraoperative optical rhinoendoscopy (b). During optical endoscopy a viewing angle is chosen corresponding to optimal visualization of the lacrimal passages during virtual endoscopy, which also enables maximal availability of lacrimal sac projection on the lateral wall of nasal cavity.

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**Fig. 4:** Screenshot of a virtual rhinoendoscopy video (a) compared to a screenshot of optical intraoperative rhinoendoscopy during transillumination (b). Transillumination of the sac with a light source inserted into its cavity does not allow sharp marking of sac walls borders and choosing of optimal site for stoma formation.

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![Fig. 4](image)

**Fig. 5:** Screenshots of optical intraoperative rhinoendoscopy before (a) and after (b) dacryocystorhinostomy formation compared to a screenshot of initial virtual rhinoendoscopy with segmentation and marking of lacrimal passages. Dacryocystorhinostomy (backfilled with dressing in image b) was formed on the basis of virtual endoscopy data lower than according to transillumination data with complete entering into the sac cavity. In case of using only transillumination data in this case the operation would be not radical due to formation of a non-drained cavity in the lower part of low positioned lacrimal sac.

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Fig. 6: Video stream of VE (left) compared to video stream of optical intraoperative rhinoendoscopy (right). In case of using transillumination data only the choice for dacryocystorhinostoma location is difficult due to technically caused inexact of lacrimal tract visualisation. Through the use of VE data the intraoperative choice for dacryocystorhinostoma location was exact.

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Conclusion

This study demonstrates high value of VE method not only as a tool of preoperative planning and surgeons training, but also as a tool of intraoperative navigation during endonasal dacryocystorhinostomy.

The possibility of vast broadening of navigation parameters unavailable both for verbal description in the text of conclusion (previous studies have shown failure of verbal description as a complete navigation guide for the surgeon during endonasal interventions) and remembering of small specific features of individual anatomy and variability of endonasal structures, course and volume of lacrimal passages during preoperative training has been clearly demonstrated.

Intraoperative use of VE demonstrated its usefulness for prevention of iatrogenic complications associated with highly individual variability of intranasal structures and, therefore, sophisticated navigation using endoscopic methods alone.

Three-dimension virtual endoscopy, long and deservedly recognized in neurosurgery, now can be effectively used in operative dacryology.

Real visualization of individual anatomy, approaching reality, increases the efficacy and quality of surgical intervention, thereby enhancing patient’s safety.

Progress has been achieved in all the directions including quantity and quality of obtained information.

Virtual reality will increase its influence in all the spheres of surgery, particularly endoscopic, as well as in the sphere of transsphenoidal endoscopic neurosurgery. (7)

Obviously, further prospects of technology development will include obtaining of augmented reality by combination of obtained virtual and real optical images, but nowadays implementation of this task is significantly limited by technical possibilities of information systems designed for this purpose.

So, the main development prospects of the method's visualization component are as follows:

1. Obtaining models of individual augmented reality for each patient. The main problem in implementation of this direction is low positioning accuracy of existing radio markers. Developing radio markers applicable for short time contact with the skin or mucous membrane and their positioning with accuracy of about 1 - 2 mm will allow for creation of individual augmented reality for each patient, thus excluding a subjective component while choosing the place for dacryocystorhinostomy formation.
2. Time spent for segmentation. Nowadays postprocessing and registration of video takes 10-15 minutes. Developing software extensions for existing solutions or specialized packs meeting the listed requirements, especially in presence of a possibility to export segmentation results as CAD models will give a possibility to exclude time factor.
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