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Visual perception of the osseous labyrinth rendered from micro-CT scans of the petrous bone

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Abstract: Grayscale images comparing to the color images may have less of visual information necessary for easy recognition of the anatomical structures. Although micro-CT scanners deliver images of ultra-high resolution, application of false-colors to the rendered structures enhance their visual perception and allow for quick delineation between them and surrounding bony matrix. This paper presents differences of imaging of the osseous structures of the inner ear labyrinth using pseudo-color volume rendering in contrast to grayscale volume rendering of the micro-CT data. Applied procedures of image processing improved significantly delineation between the bony matrix surrounding the cochlea and vestibule rendered in the pseudo-colors than in grayscale.

Key words: visual perception, image analysis, inner ear, micro-CT.

Introduction

Contemporary micro-CT scanners are capable of capturing anatomical structures with ultra-high resolution (e.g.: from 20 μm down to the subcellular dimensions of 1 μm or even less). Thereby, all tiny morphological features are precisely registered in the serial 2D images (micro-CT scans) which further can be displayed in volume rendering as the three-dimensional objects [1–6]. This makes that anatomical structures may appear very realistic. Amount of visual information contained in the images is essential for clarifying anatomical relationships inside the complex organs like the human ear.

Computed micro-tomography provides cross-sectional view of the interior of an object but the 3D reconstructions recreated from micro-CT data influence much better the perception of the observer than plain, two-dimensional images. Both volume and surface reconstructions of the anatomical structures can be viewed on the computer screen at various angles and this facilitates to orientate how the objects are embedded in the 3D space. The human ear characterizes complex anatomy because the internal components are arranged in multi-layered configuration. Therefore, 3D visualizations of micro-CT data clarify anatomical relationships between ear components and enhance the process of knowing its organization both in macro- and micro-scale [7–9]. An adequate performance of the ear components help to understand their functional integration, facilitates interpretation of the observed dysmorphologies and clearly reveals pathological changes.

Recognition of anatomical structures displayed by imaging techniques and cognitive process based on visual information contained in the image are strictly related to the mode of data collecting of the examined object. In medical studies the image acquisition of the internal organs of the human body is usually attained by the X-rays, CT or MRI. These modalities provide images showing anatomical structures in shades of gray which intensity may vary from 0–255 (0 — black, 255 — white). In contrast, the colors can much better underline morphological differences than shades of gray and the objects depicted in colors seems to be more friendly for visual perception.

The intention of this study was to present the basic idea of pseudo-coloring of CT images and reveal differences in grayscale and color display of the osseous labyrinth (the cochleo-vestibular part) rendered from micro-CT data. Pseudo-color processing is a technique that maps each of the gray levels into an assigned color via a lookup table (a predefined table of gray values which are displayed as colorized pixels). In effect, colors reflect differences in intensity of gray shades representing the image data and thus, improve the way in which objects are displayed, what enhances their recognition [10].

Materials and Methods

From the collection of the micro-CT scans of the human temporal bones a single set of micro-CT scans of the infant of approximately 2 years of age at death was selected to display osseous structures of the osseous labyrinth in the grayscale and in false-colors (they do not show natural color of the bone) by assigning a color value and an opacity value to each voxel in the dataset.

The micro-CT examination was done with the Nanotom 180 N device equipped with Hamamatsu 2300 × 2300 pixel detector produced by GE Sensing & Inspection Technologies Phoenix X-ray Gmbh. For image acquisition we set following X-ray tube parameters: I = 250 μA and V = 70 kV. Measured objects were reconstructed with the aid of proprietary GE software datosX ver. 2.1.0 using Feldkamp algorithm [11]. The spatial resolution of the reconstructed object was 16.5 μm. Obtained image data were denoised, cropped and converted from 16 bits to 8 bits by means of the VGStudio Max 2.1 software (http://www.volumegraphics.com/en/products/vgstudio-max/).

The set of reconstructed slices was displayed as a realistic 3D object using the volume rendering software CTvox supplied by the SkyScan company (http://www.brukermicroct.com/). This software enables to produce cut-away views and offers lighting effects which can be added to the scene. Application of the shadows to the rendered scene increase its depth cues and surface lighting emphasize the roughness of the objects. For better visual differentiation between the bony matrix and components of the osseous labyrinth false colors were added to the volume renderings; the blue color represented the bony shell surrounding the components of the osseous labyrinth displayed in the brown color. To enhance visual perception of the displayed anatomical structures we adjust parameters of the transfer function which controls visibility and luminance of the voxels. Thus, we could selectively adjust brightness, and opacity in the resulting rendered image, depending on the bone mineral density in the volume. Brighter shades represented more dense structures and darker shades represented less dense structures.

Further, volume rendered images were processed using Meesoft Image Analyzer which is advanced image editing and analysis software (http://www.meesoft.logicnet.dk) [12]. From the variety of image enhancement features included in this program we used color model conversion and pixel format conversion to combine images into one composite image using following expression: (Image A + Image B)*0.5 + Image B; where Image A was in grayscale, Image B was in the blue channel separated from RGB color space. Obtained composite image in grayscale characterized increased visual perception of the observed osseous structures comparing to original grayscale image of the same structures.

Results

Hereby, we present pseudo-color volume rendering versus grayscale volume rendering of the osseous labyrinth virtually sectioned on the level of the cochlea, vestibule and the internal acoustic meatus. For easier visual distinction of the displayed structures of the inner ear two different colors were attributed: the blue for the bone surrounding the cochlea and the vestibule and yellow brown for the vestibule and the cochlea seen in the cross-section (Fig. 1A). The result of converting a pseudo-color image to grayscale image presents Fig. 1B. The conversion involves loss of information: some colors that were distinct in the pseudo-color image were mapped to a single intensity of gray shades in the grayscale image what influenced considerably performance of subsequent structures of the osseous labyrinth. This is particularly noticeable between the bony matrix surrounding the vestibule and the cochlea. In this case gray values of the pixels composing the image are almost the same or very similar in their intensity. Thereby, the entire image appears rather dull and not so vivid like its pseudo-color counterpart.

By using pseudo-color CT data were visualized more effectively because the human eye can distinguish much more colures than shades of gray. In turn, removing the colors from the image caused that the overall appearance of the osseous structures became less attractive for eye (Fig. 2). In such case demarcation between the structures of the osseous labyrinth was more difficult, and small osseous components were harder to recognize than in the color image (e.g. singular canal in the grayscale image is less visible than in the color counterpart).

In the grayscale images obtained from color images we observed loss of visual information allowing easy delineation between displayed anatomical structures. This problem we solved by splitting RGB color space to separate channels and used image from the blue channel which was added to the grayscale image obtained after conversion of the color image to the grayscale. In resultant image brightness of the subsequent pixels was intensified causing that parts of the region of interest (bony matrix between the cochlea and vestibule appears as a white region) could have been selectively delineated and perceived easily though it is grayscale image. In the pseudo-color image this region was presented by the blue color (Fig. 3).

The final refinement of the image was achieved by sharpening of the rendered structures and increasing local contrast what enhances distinguishing both local and global anatomical features of the osseous labyrinth and its surrounding.

Applied procedures improved significantly delineation between the bony shell surrounding the cochlea and vestibule allowing easily distinguish differences between them through the pseudo-colors in contrast to grayscale images. This was possible because these structures attenuate differently X -rays transmitted in CT-scanner and this determines various intensity of the pixels displayed in the image as shades of gray.

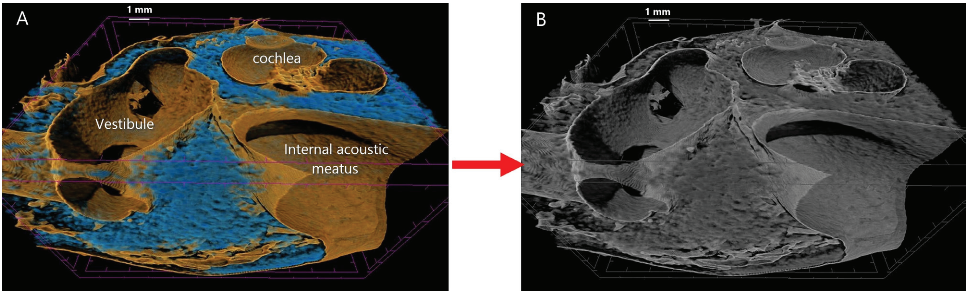

Fig. 1. Pseudo-color volume rendering cochleo-vestibular part of the osseous labyrinth seen in the cross-section converted to the grayscale image. Overall appearance of the anatomical structures displayed in gray shades seems to be less friendly for eye perception than in the color image.

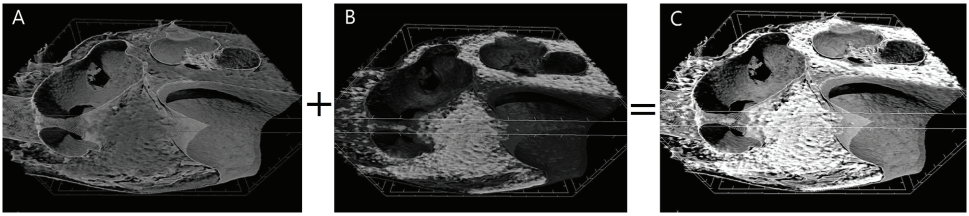

Fig. 2. Effect of blending of two images according to the formula: (Image A + Image B)*0.5 + Image B.
A — Image obtained from conversion RGB to the grayscale.
B — Rendered structures presented only in the blue channel selected from the RGB.
C — In the resultant image visual perception of the bony matrix surrounding of the cochlea and the vestibule was significantly improved though the structures are displayed in the grayscale.

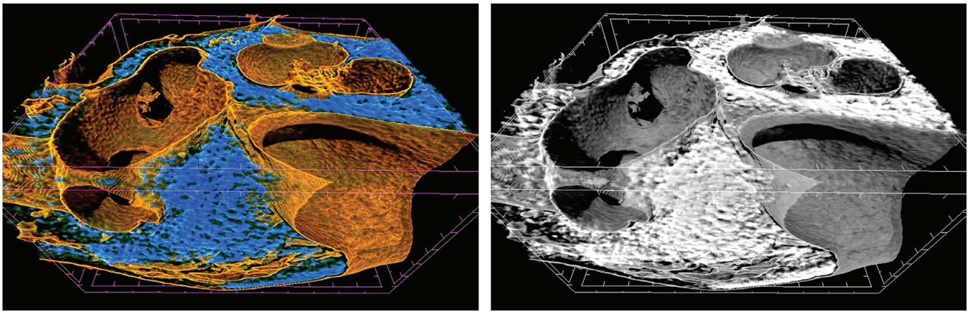

Fig. 3. Comparison of pseudo-color image and composite grayscale image. The images were adjusted for optimal visual perception of the anatomical structures. The blue color represents the bony matrix, whereas in the grayscale counterpart it was replaced by the white color contrasting to the shades of gray representing the cochlea, vestibule and the internal acoustic canal.

Discussion

Since many years computed tomography has been commonly used to assess gross morphology of the human organs. However, small osseous structures can be also shown by this method. For example, Tomaszewska *et al.* used the computed tomography to observe palatine bones which are relatively tiny structures [13]. Senel *et al.* performed morphological evaluation of the mandibular lingula using cone-beam computed tomography [14]. Andrei *et al.* applied the same method to investigate the length, three-dimensional orientation and morphological variation of the styloid process of the temporal bone [15]. In turn, Porowski *et al*. analyzed development of the human osseous labyrinth in a computed tomographic study [16].

Although modern tomographs used for clinical examinations are capable of imaging anatomical structures which dimensions are below 1 mm, imaging quality can not compare to micro-CT scans and volume reconstructions obtained from them which are highly realistic. Therefore, computed micro-tomography seems to be ideal technique for imaging ear anatomy in 2D and 3D mode, provided that the examination is performed on the isolated samples (*ex vivo*).

Up to date, micro-CT examination of the temporal bones gave satisfactory results to reveal morphology of the tympanic cavity, osseous labyrinth, and other tiny structures of the human ear like the neurovascular canals or receptors of the sense of hearing and balance both in the adult, infant samples and fetuses [17–25]. In these studies performed with the aid of the computed and micro-computed tomography the osseous structures of the middle and inner ear were presented in grayscale images.

The results of our study indicate that by attributing colors to the gray values one may significantly enhance visual perception of the rendered structures and easier recognize anatomical details. However, the osseous structures of the ear are difficult for visual differentiation by attributing colors to the defined structures because their material properties are similar. The only feature which may vary across the sample is bone mineral density. The bone surrounding the ear labyrinth consist of dense bony tissue which is more compact than in other osseous structures of the ear. According to densitometric measurements performed by Valvassori *et al.* local density of the otic capsule forming the osseous labyrinth may reach 2200H [26]. Duan *et al.* proposed for better display of the anatomical structures 3D CT imaging with volume rendering of separating, fusing, opacifying and false-coloring techniques [27]. Park *et al.* demonstrated that pseudo-color transformation increased stapes and the incudostapedial joint in CT images [28]. Such modification of the routine CT images may provide more clear anatomical basis for diagnosis and surgical operation.

Anatomical structures presented in colors seem to be more attractive for eye than grayscale images. Therefore, addition of colors to 3D reconstructions improves cognitive process aimed on learning anatomy of the ear by visual exploration of its components imaged by the computed tomography. Hence, visible gradation of colors and their various saturation facilitates recognition and comparison of the observed structures.

Conclusions

Anatomical structures are easier to discern when they are displayed in colors comparing to shades of gray. Photorealistic visualization of the micro-CT data significantly improves visual perception of the ear components. Addition of false-colors and blending with the grayscale images improved visual perception of the inner ear structures displayed in volume rendering.

Conflict of interest

None declared.

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