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Initial investigations of a special high-definition (Hi-Def) zoom capability in a new detector system for neuro-interventional procedures

S.V. Setlur Nagesh, A. Shankar, J. Krebs, J. Hinaman, D.R. Bednarek, and S. Rudin

Toshiba Stroke and Vascular Research Center, University at Buffalo, SUNY

Abstract

Real-time visualization of fine details ranging to 100 μm or less in neuro-vascular imaging guided interventions is important. A separate high-resolution detector mounted on a standard flat panel detector (FPD) was previously reported. This device had to be rotated mechanically into position over the FPD for high resolution imaging. Now, the new detector reported here has a high definition (Hi-Def) zoom capability along with the FPD built into one unified housing. The new detector enables rapid switching, by the operator between Hi-Def and FPD modes. Standard physical metrics comparing the new Hi-Def modes with those of the FPD are reported, demonstrating improved imaging resolution and noise capability at patient doses similar to those used for the FPD.

Semi-quantitative subjective studies involving qualitative clinician feedback on images of interventional devices such as a Pipeline Embolization Device (PED) acquired in both Hi-Def and FPD modes are presented. The PED is deployed in a patient specific 3D printed neuro-vascular phantom embedded inside realistic bone and with tissue attenuating material. Field-of-view (FOV), exposure and magnification were kept constant for FPD and Hi-Def modes.

Static image comparisons of the same view of the PED within the phantom were rated by expert interventionalists who chose from the following ratings: Similar, Better, or Superior. Generally, the Hi-Def zoomed images were much preferred over the FPD, indicating the potential to improve endovascular procedures and hence outcomes using such a Hi-Def feature.

Description of Purpose

Image guided neuroendovascular interventions are modern day minimally invasive treatment of cerebrovascular diseases such as strokes and aneurysms. The treatment devices such as stents and coils used during these procedures have very small feature sizes in the order of a few 100's of microns or less. During the deployment of such devices it is important to provide good live visualization of the treatment area to the interventionalist. Towards this goal two high resolution fluoroscopes based on Charge Couple Devices (HRF-CCD) and Complementary Metal Oxide Semiconductors (HRF-CMOS) were developed and previously reported [1,2]. Both of these devices were mounted on the existing flat panel detector supports using a mechanical changer unit. Whenever the high resolution capability was needed, the HRF's were deployed into the FOV using the automatic positioning system of the mechanical changer. Figure 1 shows the HRF-CMOS mounted on the changer on the

frontal C-Arm unit. Using this implementation the visualization was improved, but the workflow of using such HRF's was not clinically optimal because of the mechanical delay in positioning the HRF.

In this work we present preliminary investigations on a new proprietary detector which has a high resolution (Hi-Def) capability along with the FPD built into one unified housing whose physical appearance is similar to that of the original FPD. The new detector implementation enables rapid switching by the operator between Hi-Def and FPD modes. Semi-quantitative subjective studies involving qualitative clinician feedback on images of interventional devices such as a Pipeline Embolization Device (PED) acquired in both Hi-Def and FPD modes are presented.

Methods and Materials

Detector Description

The new detector consists of a 194 μm FPD pixel array as well as a 76 μm CMOS pixel array (Hi-Def) in a single housing unit. The image acquisition between the FPD and Hi-Def modes can be switched rapidly using an electronic switch. Figure 1b shows an image of the new detector system.

Modulation Transfer Function (MTF) determination

The MTFs of the new detector as used in the field with anti-scatter grid in place and under Hi-Def mode and the FPD mode were calculated using the edge method under RQA5 spectrum conditions. To minimize blurring due to the focal spot size, the edge is placed on the detector cover as close as possible to the detector; however, some degradation due to the space between the detector phosphor and the test tool may occur. Images of the edge are acquired using both the FPD and HiDef modes at their native pixel resolution.

Neurointervention phantom setup

An x-ray image is formed by the differential attenuation of the x-ray beam within a patient's body. During an endovascular neurointervention, the significant sources of x-ray attenuation are the human bone (skull) and the soft tissue (including human cerebral cortex). The human cerebrovasculature was simulated by 3D printing models based on an actual patient's CT angiogram. The process of generation of 3D printed models was previously described [3,4]. The bone attenuation was simulated by placing the vascular model inside a human skull. The tissue attenuation was simulated by placing a total stack of five one inch thick acrylic layers underneath the skull (simulating entrance tissue) and above the skull simulating the exit tissue. The schematic of the model setup is shown in figure 2 and the skull embedded with 3D printed phantoms is shown in figure3.

Qualitative Comparison

Objectively due to higher resolution in the HiDef mode, the images are sharper and better quality than the FPD mode images. To evaluate the extent to which this increased performance and higher resolution is preferred during a clinical intervention, various simulated clinical views of a Pipeline Embolization Device (PED) (Medtronic) were

acquired using the two imaging modes and were evaluated by two neuro-interventionists. Clinical views of the PED were simulated by placing the PED inside the neurointervention phantom. The 3D printed phantom was used as a positional reference for placement of the PED, in the Middle Cerebral Artery (MCA) and Internal Carotid Artery (ICA) regions.

Image Pair Acquisitions and display

An image pair consisting of a Hi-Def image and FPD image of the same PED object, FOV and exposure conditions was acquired using the above setup. A total of 10 different image pairs were obtained by changing PED's of different sizes, configurations and its positions in the 3D printed neurovasculature placed within the skull. Figure 4 and 5 gives an example of two different image pairs shown to the neuro-interventionalists. Fig. 4a and 5a are the Hi-Def images, and Fig. 4b and 5b are the corresponding FPD images. The images were displayed at their native resolution with a matrix size of 1024 x 1024 pixels.

Image pairs were presented to the neuro-interventionalists, who were asked to select their preferred image within the pair and were asked to rate their choice in comparison with the other image with the following three options: Similar (~), Better (>), or Superior (>>). For a fair and unbiased comparison, the position of the HiDef and FPD images within an image pair was not the same but was randomized for all the pairs and was not made known to the raters.

Results

Due to the smaller pixel size of the Hi-Def mode, the Nyquist frequency is 6.5 cycles/mm and is higher than that of the FPD which is 2.5 cycles/mm. At the Nyquist frequency of the FPD, the MTF of the Hi-Def mode was approximately 3 times higher than the MTF of the FPD mode.

The results from the qualitative image comparison study is shown in figure 6. It can be seen that both raters preferred the HiDef images over the FPD. This is in agreement with the MTF results, since due to higher resolution, the images are sharper and visually improved.

Conclusions

Due to the higher resolution of the HiDef, the images are sharper and hence are visually improved compared to the images of the FPD. This is supported by the positive results of the comparative observer preference study presented here. These results suggest that the improved imaging provided by the HRF can provide an advantage during neurointerventions. The new detector having both Hi-Def and FPD modes can offer an advantage in the clinic compared to the existing commercial FPD-only detector systems used during interventions.

References

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Figure 1.

Figure 1a: An HRF-CMOS mounted on a CHANGER on the Frontal C-Arm. In the figure the HRF is in the FOV. When not needed the HRF is taken out of the FOV by using the automatic position capability of the mechanical CHANGER

Figure 1b: New detector system both the HiDef and FPD detector in one single panel.

Figure 2.
Phantom setup to generate clinical-like view of the PED for qualitative image comparison studies by the neuro-interventionalists.

Human skull embedded with a 3D
printed phantom and PED's

Figure 3.
Human skull embedded with the 3D printed phantom

Figure 4. Sample image pairs presented to the neuro-interventionalist for a qualitative image comparison study. **A**-Hi-Def image, **B** - FPD images. The images are presented at their native resolution (1024 x 1024 pixels each). For the reader to appreciate the difference between the Hi-Def and the FPD, the stent portion of each image is zoomed in and presented under the corresponding image.

Figure 5.

Sample image pairs presented to the neuro-interventionalist for a qualitative image comparison study. **A**-Hi-Def image, **B**- FPD images. The images are presented at their native resolution (1024 x 1024 pixels each). For the reader to appreciate the difference between the Hi-Def and the FPD, the stent portion of each image is zoomed in and presented under the corresponding image.

Figure 6. Bar chart showing the options selected by the two raters for 10 image pairs. It can be seen that both the raters preferred the HiDef images over the FPD images.