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TECHNICAL NOTE

Three-dimensional imaging and cone beam volume CT in C-arm angiography with flat panel detector

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ABSTRACT

We evaluated a new 3D angiography system with a flat panel detector (FPD) for its capabilitiy to acquire volume sets during a single rotation scan and to reconstruct high spatial resolution three-dimensional and cross sectional images, namely cone beam volume computed tomography (CBVCT) images. Present status of the technique, advantages and potential applications are discussed.

Key words: • *angiography* • *tomography, X-ray computed* • *imaging, three dimensional*

Three-dimensional (3D) rotational angiography basically uses the same imaging technique with cone beam volume computed tomography (CBVCT). It is the rotational volume scanning with two-dimensional X-ray detector and cone shaped X-ray beam. This technique has been mainly used for the high contrast structures such as contrast medium filled vascular structures. Application of flat panel detector (FPD) technology to the C-arm systems may improve the image quality in both contrast and spatial resolution. Acquiring cross-sectional and 3D images by a simple C-arm system during percutaneous, endovascular or open surgical procedures with high spatial and contrast resolution can be very helpful not only to detect the unfortunate complications, but also to better understand complex anatomy.

Technique

System

In animal laboratory, two dimensional rotational projection radiographs were acquired by using a single plane C-arm angiography system with a 18×18 cm amorphous silicon FPD (AXIOM Artis dFC, Siemens Medical Solutions, Germany). System software is a patched version and not released for clinical usage. Acquired images were then transferred to a dedicated post-processing workstation (Leonardo, Siemens Medical Solutions, Germany) where a volume data set was reconstructed in a CT type data set consisting of many sections with the thickness of voxel size and visualized with volume rendering technique as 3D and multi-planar reconstruction images. The whole data acquisition is called 3D-Dyna.

Data acquisition

Basically two different imaging protocols were available for so-called 3D-Dyna with different rotation times, numbers of images acquired during each rotation. C-arm makes a single rotation around the z-axis of the object, in contrary to double rotation in 3D-DSA (mask and fill runs). In the 5-second run, rotation angle was 200^0 with 1.5^0 increment revealing 133 projections. Rotation speed was 40^0/s and frame rate was 26.6 frame/s. In the 11-second run, these parameters were 220^0, 0.8^0, 273, 20^0/s and 24.8, respectively. There were also two different dose settings for both 5- and 11-second data acquisition protocols. The system dose (at the entrance of the detector) for low and high dose settings were 0.36 mGy/F and 1.2 mGy/F, respectively. Zoom settings could also be changed, but the system was calibrated only for the zoom 0 (25 cm). The matrix of the FPD system was 1.024×1.024 (useful matrix was 960×960) and the pixel size was 0.184 (all technical information are unpublished data from the manufacturer).

CBVCT 3D image reconstruction method uses a modified well-known Feldkamp reconstruction algorithm (1, 2).

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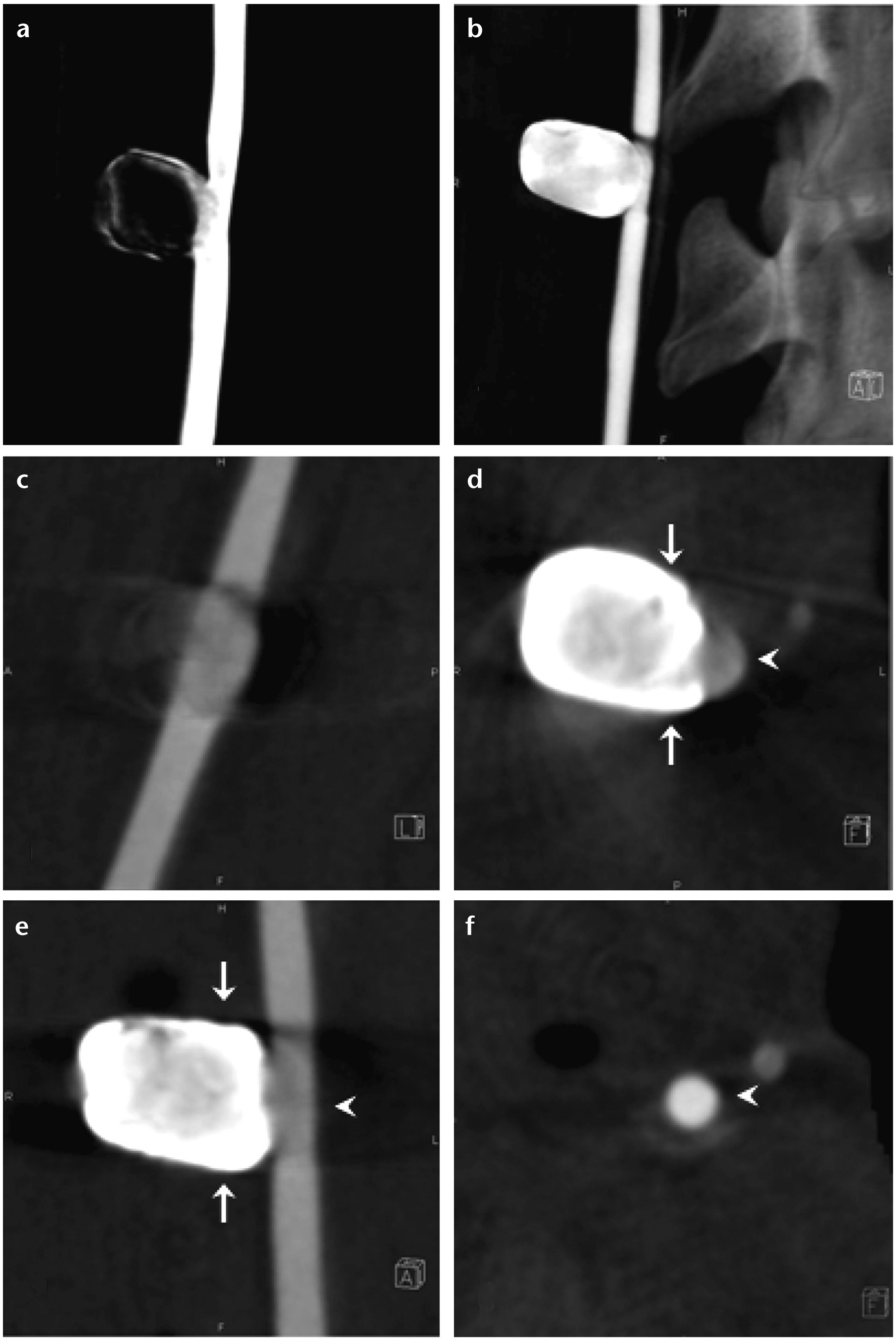

Figure 1. Experimental aneurysm created on the right common carotid artery in a dog was embolized with a liquid embolic agent. Post-embolization 3D DSA **(a)**, post-embolization 3D-Dyna with 20% contrast **(b)** are seen and, as it is not a subtracted image, neighboring structures such as cervical spine can also be evaluated **(c-f)**. Orthogonal cross-sectional images (**c:** oblique sagittal, **d:** axial, **e:** oblique coronal) reconstructed after 3D-Dyna acquisition with 20% contrast reveal the relationship between the embolic material (*arrows*) and the carotid lumen (*arrowheads*). Axial image **(d)** shows normal common carotid artery (*arrowhead*).

Image data sets for 3D-Dyna were acquired in five dogs that were studied under a different research protocol and from a human volunteer. Cranial and neck regions were studied in dogs and elbow region was chosen due to its complex bony anatomy and size for the human volunteer. Experimental sidewall aneurysms were created and embolized with a liquid embolic agent in all of the animals. 3D-DSA and 3D-Dyna imaging for the neck region and additional 3D-Dyna acquisition for the cranium were performed. In addition to high quality cross-sectional images and 3D reconstruction of the cervical spine, we could also differentiate the carotid vascular lumen and embolic material within the aneurysm and their relationship on the cross-sectional images of 3D-Dyna with 20% contrast injection after the embolization (Figure 1). Images of the dog cranium also had high spatial resolution. Truncation artifacts had occurred because the sizes of the dog's cranium were bigger than the field of view. Image quality for the bony structures, even for the complex ones such as the temporal bone, was sufficient for diagnostic purposes. However, intra-cranial soft tissue structures or the compartments could not be differentiated (Figure 2). 3D-Dyna study of the human volunteer revealed good quality axial and 3D images of the bony structures at the wrist. Although the contrast resolution was lower compared to CT, differentiation of muscle, tendon and fat tissue was possible (Figure 3).

Discussion

CBVCT has been investigated in the past two decades to evaluate its potential advantages over a fan beam CT like improved data acquisition efficiency, uniform and increased spatial resolution and better 3D CT applications. The recent development of X-ray flat panel detectors (FPD) has made CBVCT imaging feasible for practical use in a clinical setting. Other slow-rotating systems without a gantry or C-arm design have started to be tested in the maxillofacial region and for breast imaging (3, 4).

Three-dimensional computed rotational angiography, originally developed for vascular imaging, has gained a high level of acceptance among the interventional neuroradiologists (5). Three-dimensional reconstructions allow a better understanding of the complex vascular pathologies and their anatomical relationship with other important vascular or surrounding structures. The necessary data for reconstruction of 2D digital projection images can also be collected during rotational angiography without DSA. Volume scanning with 2D detector and cone beam x-ray yields isotropic voxel size and image spatial resolution. As a result, multi-planar high-resolution cross-sectional and 3D reconstructions can be obtained.

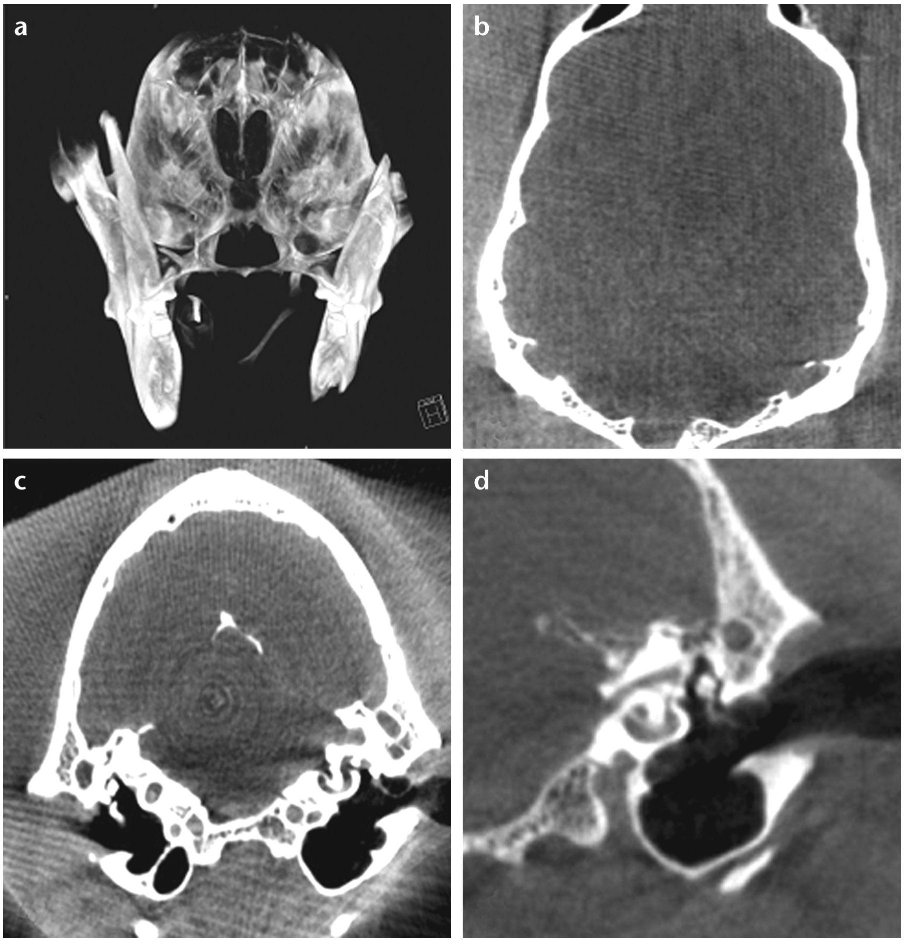

Figure 2. 3D-Dyna imaging of a dog's cranium. **a.** Three-dimensional reconstruction showing the cranium and part of the mandible from anteroposterior view. In axial **(b)** and coronal **(c)** cross-sectional images, differentiation of the brain parenchyma from ventricles or subarachnoid space is not possible due to low contrast resolution. Magnified axial view at the level of the left temporal bone **(d)** demonstrates middle ear ossicles and inner ear structures with high spatial resolution.

Image intensifier or FPDs can be used as a detector. FPDs have been shown to yield higher spatial resolution than the image intensifier detectors (6). Isotropic scanning voxel size leading to true isotropic spatial resolution is an inherent and major advantage of FPD-based cone beam tomographic imaging. True isotropic spatial resolution still cannot be achieved even with the state-of-the-art 16-slice spiral CT systems. Longitudinal and in-plane resolution that can be achieved with such systems are 0.6 mm and 0.5 mm, respectively (7). However, spatial resolution in a comparable custom-made system with a FPD at a pixel size of 0.254 mm was reported as 0.35 mm (6). The system that we used has a spatial resolution of 0.20 mm (manufacturer's data). Actually, having a volume data set with a true isotropic resolution makes two different resolution definitions (axial or in-plane and longitudinal or z-plane) unnecessary. As a result, traditional axial slice may lose its importance. Instead, interactive viewing and manipulation of isotropic volume images and filming the selected stored images will be the routine radiological practice. Furthermore, one can expect improvement in image quality with FPD because of the following reasons: FPD has no image distortions like in the image intensifiers influenced by the Earth's magnetic field. The higher bit depth (14 vs. 12) may be transferred into higher detection dynamics and they are also less sensitive to over exposure, which causes a glaring or blooming effect on image intensifier systems. Higher detective quantum efficiency may also lead to better dose usage.

Although sophisticated tools in the era of endovascular surgery have been developed, procedure related complications such as vessel rupture in aneurysm treatment, are still important causes that increase mortality and morbidity. Sometimes vessel rupture can be very obvious during the angiography and one can easily see the extravasations of contrast medium. In other cases, it can be detected by unexpected shift of the vascular structures by acutely developing hematoma, while minor perforation and subsequent self-limited subarachnoid bleeding can easily be overlooked. This situation can be the cause of the worsening of the patient's condition after an otherwise uneventful endovascular procedure. A cross-sectional imaging method with a high spatial and contrast resolution, readily available in angiography suites and allowing imaging of the intracranial brain parenchyma, subarachnoid space and ventricular system, can be very helpful in such undetermined situations. Further therapeutic measures can be tailored according to the result. Prompt patient transfer from angiography suite to the operating room would save very precious time for the complicated patients. Other advantages of combined systems (angio-CT) are also valid for the discussed system. For example, cross-sectional and 3D bone images, in addition to fluoroscopic images, would be very beneficial for the spinal interventional procedures. This is actually the same rationale that those combined systems evolved from.

C-arm based or different design CBVCT systems have great advantages in imaging of trauma cases or in orthopedic surgery operating room. Acquiring 3D and cross-sectional images in addition to conventional 2D images with the same system certainly gives a chance to physician to better understand fractures and results of their therapeutic reconstructive attempts on bony structures. Similar work has been done by El-Sheik et al. and is called computed rotational osteography (8).

The problem related to the geometry of the x-ray beam appears at the image reconstruction level. Cone beam and streak artifacts may decrease the image quality and contrast resolution, but at the quality level that has been

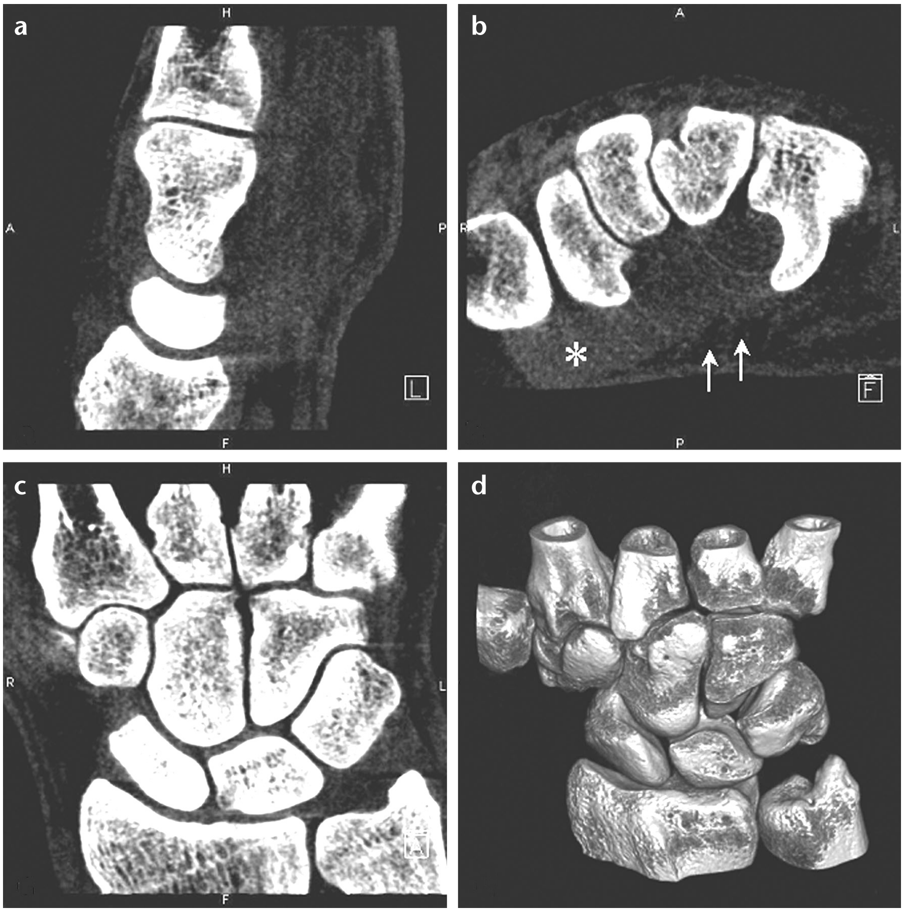

Figure 3. Sagittal **(a)**, axial **(b)** and coronal **(c)** cross-sectional images reconstructed after 3D-Dyna acquisition from a human wrist. High spatial resolution gives good quality bone images. Contrast resolution is good enough to differentiate muscle and tendons (*asterisk*) from the fat tissue (*arrows*). **d.** Three-dimensional reconstruction of the same anatomic region delineates complex bony anatomy.

achieved with the present setup, cone artifacts play no significant role. FPD system has an advantage on image intensifier systems in contrast resolution parameters especially at lower doses within clinical range (6), but, nonetheless, we still could not differentiate brain tissue, ventricular system and subarachnoid space in dogs with our system. With 273 projections, the number of streak artifacts limits the contrast resolution. The streak artifact level will improve as soon as there will be protocols available with more projections. Obviously, temporal resolution of the system is not comparable to the multi-slice CT due to the relatively slow C-arm motion. We think that the low temporal resolution does not significantly affect the potential clinical benefits and applications of a C-arm based cone beam CT method in skeletal system or in interventional radiology procedures.

Major limitation of the currently available system used in this study is the small field of view. Large objects cause truncation artifact in cross-sectional images but it can easily be overcome by increasing the size of the FPD. Total time necessary to acquire the data set and image reconstruction depends on the protocol details, but it was around five minutes for the 11-second (high dose) acquisition with medium field of view and 256×256×256 image reconstruction matrix including the data transfer. With the continuous improvement in computer technology, this would probably decrease significantly in near future.

Although the acquired cross-sectional and 3D images were in good quality with high spatial resolution, further studies in phantoms, animals and patients should be conducted to validate the technique for clinical applications. We believe clinical practice will extend the limits of the application spectrum of this imaging technology.

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