Impact of Multidetector CT on 3D CT Angiography

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Abstract

3D Computed Tomographic Angiography (CTA) is a noninvasive volumetric imaging technique increasingly used for evaluation of vascular system. The introduction of Multidetector CT (MDCT) has increased scanning speed, allowing shorter acquisition time, greater volume coverage and decreased contrast requirement while diminishing respiratory motion artifacts. Thin-slice collimation protocols are routinely used which generate isotropic 3D voxels that improve image quality. The ideal CTA study requires scanning at peak vascular enhancement for optimal opacification of arteries with separation of arteries and veins. MDCT has enabled complete lower extremity inflow and runoff studies with a single injection, as well as thin-section CTA covering the entirety of the Carotid arteries and Circle of Willis. Sixteen row MDCT has increased scanning speed further facilitating the development of novel applications such as coronary CTA. CTA when performed with MDCT offers a “one scan – many views” option useful in imaging vascular diseases. CTA has important advantages over conventional angiography, such as reduced risk, diminished time and better patient acceptance. With MDCT, 3D CTA is crossing vessel tortuosity and evaluation of vessel fragility.

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Introduction

CT angiography (CTA) is one of the promising noninvasive techniques available for imaging of the vascular system. Offered as an in-built feature in most CT machines, this powerful tool has applications ranging from detection of cerebral aneurysms, quantifying coronary artery disease and assessment of aortic and peripheral vascular disease. CTA is also exploring newer applications like plaque imaging and vessel tortuosity evaluation.

Impact of Multidetector CT

In MDCT, the single detector array of spiral CT is replaced by multiple rows of detector arrays, permitting registration of multiple channels of image data. A four slice and sixteen slice scanner have a detector row array collecting four and sixteen channels of image data during each gantry rotation. Besides the scanner's number of channels, gantry rotation time determines the number of slices that can be acquired per unit time. These developments in MDCT have benefited CTA applications overwhelmingly [1]. Ideal CTA achieved by a combination of a) the use of 18G venflo in antecubital vein, b) large volume of high concentration nonionic contrast (120-150cc), c) rapid intravenous injection of contrast using pressure injector at 3-4ml/sec, d) threshold selection of 150 HU (Hounsfield Units), and f) proper timing from start of injection to start of

scanning. Appropriate timing is assisted by two methods [2]. A *semiautomated* method obtains a series of static scans while injecting 15 to 20ml of contrast at anticipated injection rate. In *automated* method image acquisition is triggered when a preset enhancement threshold is reached within a preselected region of interest. Saline bolus chasers of 50 to 70ml are employed to force the contrast through the tubing, venous system and between injection site and heart thereby prolonging the plateau phase of enhancement [3].

Material and Methods

Forty-one patients were subject to CTA studies. Aortoiliac stenosis was the largest group with nine patients. The other CTA studies included the cerebral, carotid, cardiac, pulmonary, subclavian, aortic, hepatic, renal, femoral, popliteal and arteries of the extremities.

All CTA studies were performed using a Multidetector technique with a Somatom Sensation 4 Multidetector scanner (Siemens, Erlangen). Equipped with a flying spot adaptive array matrix and a gantry rotation time of 0.5 sec, the system is augmented with Medrad Vistron pressure injector and CARE Bolus software, facilitating an automated run with a selected threshold of 150 HU. 300mg I/ml of non-ionic contrast media was injected through a 18 G antecubital venflo, with a pressure injector at a rate of 3 cc/s.

The CTA Protocol has many variables and included type of scanner, region of scan, slice thickness, slice collimation, pitch, coverage, FOV, Matrix, volume and rate of contrast.

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Image reconstruction was accomplished by using a soft tissue kernel and 180-degree linear interpolation. Reconstructions were performed with 50% overlap, resulting in an average of 900 images per study. The individual scans were reformatted separately on a workstation. Window width of 1000 and window level of 500 were used routinely for viewing all gray scale 2D image data. For steni-grafts, the window levels of 200-600 HU and widths of 600-1200 HU were employed.

Discussion

The introduction of MDCT has increased scanning speed allowing shorter acquisition times, greater volume coverage and decreased contrast requirement while diminishing respiratory motion artifacts. Thin-slice collimation protocols are used which generate isotropic 3D voxels that improve image quality. Optimization of contrast enhancement is beneficial and offers separation between the arterial and venous phases. MDCT has enabled lower extremity inflow and runoff studies with a single injection, and thin section CTA covering the Carotid arteries and Circle of Willis. Sixteen-row MDCT has increase scanning speed even further facilitating the development of applications such as coronary CTA. CTA when performed with Multidetector CT offers a “one scan-many views” option useful in imaging vascular diseases. MDCT offers evaluation of CTA volume data, which depict luminal perspective, mural anatomy, ostial and major branches take off and measurement. A promising fifth technique is Virtual Angioscopy [4].

Multiplanar Reformation (MPR) is a 3D technique utilizing stacked axial sections to generate imaging volume. A reformatting algorithm is applied creating a single section 2D and thick slab 3D images (Fig 1). “Curved” uses a curved line in a single-voxel-thick plane extruded by computer algorithm through the entire data set. The resultant “curved plane” is flattened and displayed as a 2D composite image representing the target vessel. Shaded Surface Display (SSD) offers opaque surface representation of vessels by user selected range of Hounsfield units with upper and lower thresholds. With the surface determined, the remainder of the data is discarded. Surface edge contours are modeled as a collection of polygons and displayed as a shaded surface whose relative depth is provided by shading from a computer-generated light source. Light effects give depth to the image. Maximum Intensity Projection (MIP) is used for angiographic display of CT and MRI data. MIP displays brightest voxel along a line from the viewer’s eye through the image, while darker voxels in front or behind are not displayed. MIP allows accurate evaluation of the vessel diameter compared with SSD. Volume Rendering (VR/VRT) is the preferred method for 3D post processing. Each voxel within a data set is characterized by brightness, color and opacity

that forms a comprehensive vascular image of arteries and veins [5]. By utilizing all voxels within a volume, VR avoids extensive loss of information, clarifies vessel definition, diminishes vessel-bone interface difficulties and circumvents loss of perspective. Virtual Angioscopy (VA) provides “on the fly” endoluminal evaluation view “within” the vessel (Fig 3). It is useful in evaluating vascular orifices and assessing vascular stenosis and aneurysms [6].

CTA is increasingly used for a variety of clinical applications. At the Circle of Willis, CTA with MDCT provides information on the number, location, extent of aneurysm with exo and endomorphology and presence of intraluminal thrombi. A recent study, showed that the isotropic feature of MDCT increased the sensitivity for depiction of intracranial aneurysms 3 mm or larger [7]. While MPR is used for quantitation of aneurysmal sac with dome-to-neck ratios, evaluation of neck and parent artery dimensions, curved oblique MPR images are useful in characterising obliquely oriented aneurysms. VR images depict spatial orientation of the aneurysm and delineate the relationship of aneurysm to bone, while VA offers endoluminal view of the Circle of Willis and the aneurismal neck.

Carotid endarterectomy benefits symptomatic patients with carotid stenosis of 70% or more. In our study, CTA displayed the entire carotid system with quantification of stenosis and display of plaque composition (Fig 2). A recent study indicates that VR is as accurate as SSD in the evaluation of carotid arterial bifurcation, but better in accurately grading calcified stenosis [8]. However, artifactual luminal distortion or eccentricity affects measurement of stenosis in thicker slices and vessels oriented perpendicular to the z-axis. Studies suggest measures to increase accuracy with CTA by using minimum diameter in and out of the stenosis [9].

Noninvasive imaging of cardiac system and coronary arteries is possible with MDCT which permits this by rapid multiple image acquisition at 125-250msec after administration of beta blockers which lower heart rate and reduce motion artifacts [10]. To the 3D data set, obtained under ECG trigger, rendering is performed by oblique and curved MPR and VR to visualize the coronary arteries. Different cardiological applications like stent assessment, stenosis evaluation and follow-up of bypass are possible. CTA of coronaries requires a large number of projection angles for review of whole vessel volume [11].

MDCT plays an important role in evaluation of aortic aneurysms with or without dissection [12]. The technique is useful in pre and postoperative abdominal aortic stent graft evaluation [13]. In stent graft evaluation,

Fig. 1 : Left subclavian aneurysm due to a cervical rib in a 35 year lady. a) coronal multiplanar reconstruction (MPR) shows a left subclavian artery aneurysm extending into proximal axillary artery, b) 3D volume rendered (VR) technique depicts the complex relationship between aneurysm, cervical rib and left clavicle rib.

Fig. 2 : Bilateral carotid stenosis in 65 year old symptomatic man: a) Axial CT demonstrating heavily calcified atheroma at both common carotid bifurcation; b) coronal 3-D VR technique display calcification and contrast within both carotids; c) Carotid DSA delineates 75% stenosis at left and 50% at right; d) virtual angioscopy of distal left CCA with endoluminal view of calcified plaque; e) Coronal MPR depicting the aortic arch, carotids and Circles of Willis in a single image.

MPR generated images displayed thrombosed aneurysm and stent graft. Curved MPR showed aneurysm and stent graft in a single image in multiple planes. MIP demonstrated the stent graft, but superimposing veins such as superior vena cava and azygos vein interfere. In SSD, aneurysms are well depicted. In an elderly hypertensive with an aortic arch aneurysm treated with Stent Graft, volume rendered images showed no evidence of stent graft migration, thrombosis kinking or evidence of endoleak. CTA offers noninvasive diagnosis of acute and chronic pulmonary embolism. MDCT augments this by demonstrating middle and peripheral zone pulmonary arteries better with a homogeneous

Fig. 3 : Bilateral common iliac artery aneurysm in a 60 year hypertensive male. From left top corner are a) Coronal 3D VR of the aortoiliacofemoral segment showing aneurysm of both common iliac arteries with "S" shaped tortuosity of the right common iliac, b) Virtual angioscopy shows endoluminal perspective of widened right common iliac artery; c) Coronal MPR displays adherent mural thrombus with calcific wall.

contrast material column in pulmonary arteries [14]. It is approximately 90% sensitive (60%-100%) and 90% specific (80%-100%) in diagnosis of proximal pulmonary embolism in the main, lobar and segmental arteries, but less accurate in imaging emboli peripherally in subsegmental arteries.

CTA of liver requires two phases of data acquisition, an arterial phase (25s delay) and a portal venous phase (60s delay) [15]. VRT is considered the most important rendering technique in pre-operative planning for hepatic resection, evaluation of portal vein patency, liver volume generation and pre-TIPS placement [16]. In post transplant cases CTA with MDCT detect potentially lethal vascular complications like hepatic and portal vein stenosis and hepatic artery thrombosis in the transplant donor or recipient.

3D volume-rendered CTA with MDCT reliably and accurately depict the number, size, course and relationship of renal vascular pedicle in evaluation of pre and post renal transplant cases [17]. CTA is used for evaluation of arterial disorders such as renal artery stenosis, renal artery aneurysm, dissection, venous disorders such as shunts, thrombosis and intravascular tumor extension [18]. CTA is helpful in postoperative, post angioplasty and stent placement patients and for evaluation of complications like urinoma, pseudoaneurysm and perinephric hemorrhage.

3D CTA accurately identifies vascular invasion in Pancreatic cancer. In Whipple procedure, MDCT defines presence of invasion into the superior mesenteric artery and vein [19]. MDCT provides a dynamic evaluation of the mesenteric vasculature and facilitates

the diagnosis of bowel ischemia and inflammatory bowel disease, by detecting low-flow states or embolic vessel occlusion. Visualization of collateral vessels between the coeliac, SMA and IMA suggest chronic ischemia.

In extremity CTA, MDCT augments the core issue of optimal contrast opacification by (a) cephalocaudad scanning of almost 120cm, (b) duration of acquisition interval being integrated with injection interval and (c) adequate volume of highconcentration contrast used for vessel opacification. Each vascular segment is evaluated for stenosis, occlusion and aneurysm (Fig 3)[20].

Pitfalls arise from imperfect scanning technique such as suboptimal timing of contrast, partial volume effect, too wide a spacing of reconstructed slices, vascular superimposition and inadequate functional analysis. Large amounts of iodinated contrast (100-150ml) is a problem in patients with impaired renal function. Outsized data handling is a problematic area created by acquisition of thin slices at 1mm intervals and is addressed by using cine mode, multiplanar reconstruction and interactive realtime volume rendering.

Specific properties of 3D display techniques like threshold-dependence in SSD or overlying structures in MIP result in artifacts. The limitations of MIP and SSD lie in forfeiting most of the data in order to increase image processing speed. Skeletal structures have to be removed prior to MIP reconstruction, which requires time-consuming editing owing to bones and opacified vessels having similar HU numbers. Distances in CPR cannot be measured since distances are referenced to the curve and to Cartesian coordinate system of planar images.

Conclusion

CTA is a “front end” non-invasive vascular imaging tool, providing high quality vascular images that determine the choice of treatment. With MDCT, the increase in imaging speed and resolution and improved processing made CTA applicable to a range of clinical situations. The new rendering techniques depict the entire length of vessels in many planes and offer “on the fly” angioscopy images. In the near future continuing advancements in scanner and image processing technologies will further push the frontiers of CTA applications.

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