Vascular applications of Spiral CT : an initial Experience

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Abstract

Since the clinical introduction of computed tomography (CT) in the mid 1970s, several technological and clinical advances have improved image quality and reduced scanning time. During the past decade technological breakthroughs have ushered in an exciting advance in medical imaging : spiral CT. Spiral CT technology with its high speed and volumetric data acquisition has spawned a new vascular imaging technique - spiral CT angiography which is noninvasive, accurate, faster and less expensive than conventional angiography. We report our experience of having performed 100 CT angiographies with 3-D reconstructions of various vascular territories of the body. Details of technique of data acquisition, methods of 3-D reconstruction and clinical applications are discussed.

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Key Words : CT angiography; Spiral CT; Vascular imaging

Introduction

CT angiography is a relatively new and important application of spiral CT that permits an accurate depiction of the vascular structures in 3-dimension with complete separation of superimposed structures. Catheter angiography was developed in 1953 and since then has been used extensively; however this technique is invasive, expensive and has an associated risk of 1.5 to 2% of significant morbidity and mortality [1]. These disadvantages led to the development of a number of other vascular imaging techniques such as colour flow doppler imaging and magnetic resonance angiography which are non-invasive. Over the last few years after the advent of spiral CT, CT angiography has become an important technique for evaluation of vasculature.

Although the spatial resolution of CT angiography is less than that of conventional catheter angiography, it can be used to assess arteries as small as 2 mm in diameter, moreover the 3-D reconstructed images can be viewed from an unlimited number of angles [2]. These advantages along with the noninvasive nature of the technique and reduced scanning time have brought CT angiography into prominence in the arena of vascular imaging.

Material and Methods

A total of 100 CT angiographies were performed during a ten month period from June 2001 to March 2002 on patients ranging from 15 to 75 years of age. The investigations were carried out on a Philips Tomoscan AV spiral CT scanner with a gantry rotation period of one second.

The procedure was explained to the patient and an informed signed consent was obtained. The patients were specifically

Table 1

Region wise distribution and clinical indications of CT angiography (N=100)

Region	Indications	No of patients
Intracranial circulation		
	Subarachnoid haemorrhage	2
	Evaluation of post clipping status of aneurysm	2
	Vertebro-basilar dolichoectasia	1
	Postembolisation follow up of AVM	2
	CT venography for dural sinus thrombosis	2
	Vascularity of intracranial tumours	3
Extracranial carotid arteries		
	Evaluation of significant carotid stenosis on Doppler	3
	Evaluation of carotid artery thrombosis due to neck malignancy	3
	Evaluation of vascularity of neck masses	2
Thoracic aorta		
	Post stenting evaluation of coarctation of aorta	1
	Evaluation of Takayasu's disease	1
	Evaluation of aneurysm of thoracic aorta	2
	Evaluation of dissection of thoracic aorta	3
Pulmonary arteries		
	Detection of pulmonary thrombus	2
	Follow up of pulmonary thromboendarterectomy	1
Abdominal aorta		
	Evaluation of abdominal aortic aneurysm	6
	Post vascular graft assessment	2
Renal arteries		
	Potential renal transplant donors	40
	Evaluation of renal artery stenosis	8
	Post transplant evaluation of anastomotic site	2
Iliac arteries		
	Evaluation of lower limb claudication	2
	Evaluation of distal arteries in abdominal aortic aneurysm	6
Splanchnic venous system		
	Evaluation of portal venous system in portal hypertension	3
	Evaluation of patency of spleno-renal shunt	1

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Table 2**Protocol for CT angiography of various vascular territories**

Region	Slice thickness (mm)	Table speed (mm/s)	Coverage (mm)	Contrast (ml)	Rate ml/s)	Delay (s)
Intracranial						
Circulation	1	2	40-50	90	3	19-21
Carotid arteries	2	3	60	100	4	18-20
Thoracic aorta	3	5	150-200	120	5	Predict
Pulmonary arteries	3	5	150	120	4	20-22
Abdominal aorta	3	5	150	120	5	Predict
Renal arteries	3	5	120	120	5	23-25
Iliac arteries	3	5	150	120	5	Predict
Splanchnic veins	3	4	120	150	5	85

educated about the importance of total breath holding during the entire period of CT scanning. The various vascular regions studied by CT angiography are depicted in Table 1.

Technique : The fundamental principles of CT angiography include acquisition of raw data subset, image processing and finally image display. **Spiral CT acquisition :** A preliminary non-contrast axial CT scan with 5-10 mm collimation depending on the region to be studied, was performed to localize the volume of interest and to detect any abnormal vascular calcification. After localization of the scan coverage, volume scanning using “predict scan technique” or “timed delay injection of contrast” was done. The scanning parameters along with volume and rate of contrast injection varied depending on the region to be studied and the protocols used are depicted in Table 2. The axial images obtained were reconstructed at 1-2 mm intervals and sent to a work station where 3-D reconstruction and vascular mapping were done using Shaded Surface Display (SSD) and Maximum Intensity Projection (MIP) protocols.

Image processing : The aim of image processing is to obtain images which resemble conventional angiographic images and accurately depict the vascular anatomy. The advantage of volumetric spiral CT acquisition is that 3-D images can be generated, which can be viewed from innumerable angles, such views that are impossible with conventional catheter arteriography. The techniques used for 3-D reconstruction and display in the present study were SSD and MIP.

Results

The results of CT angiograms of 100 patients under study, 76 males and 24 females, were analysed and the abnormalities detected in various vascular territories are recorded in Table 3.

A total of 12 CT angiograms of the intracranial circulation were performed out of which 5 were normal and 7 had various abnormalities which included aneurysm of the left middle cerebral artery (Fig 1) and vertebrobasilar dolichoectasia. 2 patients suspected to be having cerebral venous thrombosis were subjected to CT venography of the brain, however, the study was normal (Fig 2). CT angiography was performed in 2 patients with aneurysm of the right middle cerebral artery who underwent clipping to assess the status of the aneurysm

Table 3**Analysis of results of CT angiographic studies (N=100)**

Vascular territory	Abnormality detected	No
Intracranial circulation	Aneurysm of MCA (Lt)	1
	Aneurysm of basilar tip	1
	AV malformation (Lt parietal lobe)	1
	Vertebro basilar dolichoectasia (Lt)	1
	Moderately vascular Rt parietal glioma	1
	Status of clipped aneurysm (normal)	2
	Dural sinus thrombosis	0
Carotid arteries	Normal	5
	Atherosclerotic stenosis of CCA (Rt)	3
	Thrombosis of CCA	2
Thoracic aorta	Normal	3
	Coarctation of aorta (post stenting)	1
	Evaluation of aneurysm of thoracic aorta	2
	Dissection of thoracic aorta	1
Pulmonary arteries	Normal	3
	Pulmonary thrombus	1
	Follow up of pulmonary thrombendarterectomy	1
Abdominal aorta	Normal	1
	Infrarenal abdominal aortic aneurysm	6
Renal arteries	Normal vascular graft	2
	Renal artery stenosis	6
	Pre-hilar branching	2
	Accessory arteries	8
	Accessory veins	6
	Retro-aortic renal vein	2
	Normal (renal donors)	24
	Normal post transplant anastomotic site	2
Iliac arteries	Diffuse atherosclerotic disease	2
	Normal iliac arteries	6
Splanchnic venous system	Portal hypertension with gastric varices	2
	Normal spleno-renal shunt	1
	Normal splanchnic venous system	1

and both revealed normal post operative appearance.

CT angiogram of the extracranial carotid arteries was done in 8 patients. Out of these, 3 were confirmed to be having haemodynamically significant stenosis on CT angiogram, the degree of stenosis was then graded on the four point scale. Thrombosis of the external carotid artery was detected in 2

Fig. 1 : CT angiogram (MIP) showing bilobed aneurysm of the left MCA

Fig. 2 : CT venogram (MIP) showing normal deep and superficial cerebral venous system

patients and 3 were normal.

CT angiography of the thoracic aorta was performed in 7 patients out of whom 2 patients had aneurysm of the arch of aorta, one had De Bakey type 2 dissection and 3 were normal. One patient who had coarctation of the aorta and stenosis of the left subclavian artery with anomalous origin of the left vertebral artery from the aortic arch and had undergone endovascular stenting was evaluated by CT angiography which revealed residual stenosis of the left subclavian artery and normal appearance of the vascular stent (Fig 3).

CT angiography of the pulmonary arteries was performed in 3 patients, one patient was detected to be having a large thrombus in the left pulmonary artery and the other 2 were normal.

A total of 8 patients underwent CT angiography of the abdominal aorta. Out of these, 6 were confirmed to be having

Fig. 3 : Shaded surface display (SSD) of CT angiogram of aortic arch showing endovascular stent and residual stenosis of left subclavian artery with anomalous origin of left vertebral artery

Fig. 4 : CT angiogram (SSD) showing a large infrarenal abdominal aortic aneurysm

infra-renal abdominal aortic aneurysms and were taken up for surgery (Fig 4). CT angiography of the abdominal aorta was also performed in 2 patients who had undergone vascular grafting for infra-renal abdominal aortic aneurysm to assess the patency of the graft, which showed normal post operative appearance.

The maximum number of CT angiograms done in this study was that of the renal vasculature. A total of 50 renal angiograms were done out of which 8 were for evaluation of

Fig. 5 : CT angiogram (SSD) in a renal donor showing normal appearance of the renal vasculature

Fig. 6 : Post renal transplant CT angiogram (MIP) showing normal anastomotic site of the renal artery with the left external iliac artery

suspected renal artery stenosis, 40 for pre-operative assessment of potential renal donors (Fig 5) and 2 to assess the patency of the anastomotic site following renal transplant (Fig 6). Renal artery stenosis was confirmed in 6 patients, with 2 being normal. All the 6 patients diagnosed as renal artery stenosis underwent surgical intervention with good results.

Fig. 7 : CT angiogram of the iliac arteries showing multiple stenotic lesions in both the iliac and femoral arteries due to diffuse atherosclerotic disease

6 patients who had abdominal aortic aneurysm underwent CT angiography of their iliac arteries also for assessment of the status of the vessels, which was normal. 2 other patients who had lower limb claudication underwent CT angiography of the iliac arteries which revealed multiple areas of stenosis of the external iliac and femoral arteries due to calcified plaques as a result of diffuse atherosclerosis (Fig 7).

A total of 4 patients underwent CT angiography of their splanchnic venous systems. Out of these, 2 were detected to be having evidence of portal hypertension with dilated porto-systemic venous anastomosis (Fig 8), one patient had a normally functioning post operative spleno-renal shunt and one was normal.

Discussion

Although catheter angiography and specifically digital subtraction angiography (DSA) is considered the gold standard in the evaluation of intracerebral aneurysms and subarachnoid haemorrhage secondary to suspected aneurysmal rupture, this technique is time consuming, invasive and carries a complication risk of about 1% and 0.5% risk of persistent neurological deficit [3]. Moreover, catheter angiography performed during the first six hours of bleeding has been associated with an increased rebleeding rate [4]. CT angiography is better than catheter angiography in the characterization of aneurysms, as it provides detailed anatomy of the dome, neck and vessel of origin of the aneurysm, this information is useful in determining the modality of treatment whether endovascular or surgical. When

Fig. 8 : CT portovenogram (MIP) in portal hypertension showing dilated splenic and portal veins with multiple dilated portosystemic anastomotic channels

endovascular treatment is contemplated it is important that accurate assessment of the aneurysm sac is made in relation to the neck size, presence of calcium and parent vessel caliber as these factors directly influence the selection of embolisation material [5], this information can only be accurately provided by CT angiography with 3-D reconstructions.

With the advent of better imaging facilities the detection of carotid artery disease has increased. Although catheter angiography is accepted as the imaging modality of choice for estimating carotid artery disease, a number of recent studies have indicated that the risks of catheter angiography are equal to or even greater than the treatment itself [6]. Moreover, eccentric or irregular stenosis may not be optimally assessed due to limited number of views available with conventional angiography. CT angiography has shown to have a sensitivity of 88-100% in estimating severe stenosis and occlusion, as it can provide infinite views for accurate estimation of eccentric or irregular stenosis [7]. Recent studies by Mark et al [8] have shown that in the estimation of carotid stenosis, CT angiography has a definite superiority over MR angiography, especially in estimating high grade stenosis and occlusions. MR angiography tends to overestimate stenosis when there is turbulent flow due to loss of signal as MR angiography is dependent on flow characteristics and not volume of the blood. CT angiography also gives higher sensitivity and specificity as compared to colourflow Doppler imaging in differentiating severe stenosis from complete occlusion; this is of paramount importance from the

therapeutic point of view as severe stenosis is an indication for carotid endarterectomy whereas complete occlusion is a contraindication.

Noninvasive evaluation of thoracic aorta and pulmonary arteries is now possible with CT angiography. Evaluation of post surgical status of the arch of aorta following stenting can only be achieved with CT angiogram as these patients are unsuitable candidates for MR angiography and catheter angiography is invasive and less accurate. CT angiography has been found to be 100% sensitive and 96% specific in the detection of thrombus in the main, lobar and segmental pulmonary arteries [9] and is also a valuable means of evaluation of the pulmonary arteries following thrombendarterectomy.

Evaluation of abdominal aortic aneurysm requires an accurate pre-operative anatomy of the abdominal aorta especially the relationship of the aneurysm to the major aortic branch vessels, presence of any accessory renal arteries, assessment of renal artery stenosis if any. All this information can be provided to the vascular surgeon through a single spiral CT angiography, which also has an added advantage of detecting the presence of calcium and assessing the true diameter of the aneurysm and not merely the patent lumen as in catheter angiography. CT angiography can accurately assess vascular grafts and stents and can readily confirm the patency of the revascularised segment. The relationship of the metallic stents to the aortic branch vessels can be easily appreciated and the presence of metallic clips creates only minimal interference in image quality. In the present study 2 cases of post operative vascular grafts were successfully evaluated by CT angiography and both showed patent lumen.

Catheter angiography has been the reference standard for diagnosing renal artery stenosis, however, CT angiography is a promising technique for identifying or excluding haemodynamically significant stenosis. It is 92% sensitive and 83% specific for diagnosing greater than 70% stenosis of the renal artery and 80% accurate in grading the severity of renal artery stenosis on a four point scale [10]. In cases of severe stenosis a discontinuity in the vessel can be observed on CT angiography, however, stenosis and not complete occlusion can be inferred by vascular opacification distal to the stenosis.

Comparison of CT angiogram of the renal donors and per-operative findings revealed 98% accuracy in the detection of renal arterial system anomalies, with only one accessory renal artery being missed on CT angiogram which was detected per-operatively. Analysis of the venous and parenchymal findings on CT angiogram and their comparison with per-operative

findings revealed 100% accuracy. 2 post renal transplant patients were subjected to CT angiogram to rule out stenosis at the anastomotic site. Both the studies showed normal patency of the anastomosis of the renal artery with the external iliac artery. CT angiography is the only imaging modality providing fast, non-invasive, inexpensive and accurate pre and post-operative anatomy of the renal parenchyma and vasculature.

Evaluation of the status of the iliac arteries is mandatory prior to vascular grafting or stenting of abdominal aortic aneurysms. CT angiography enables visualization of the distal abdominal aorta to the bifurcation of the femoral arteries in a single 30-40 second scan. Lawrence et al, have found that correctly performed CT angiograms have a sensitivity of 93% and a specificity of 96% in diagnosing significant stenosis of the iliac arteries as compared to catheter angiography [11]. In evaluation of lower limb claudication, CT angiography accurately demonstrates the presence of diffuse atherosclerotic disease, calcified plaques, evaluates the degree of aorto-iliac stenosis and important collateral arterial supply from the internal iliac, lumbar, intercostal and contralateral iliac arteries.

The pre and post-operative assessment of the splanchnic venous system was earlier performed by injecting contrast directly into the spleen or via an arterial catheter into the superior mesenteric or splenic artery. With these invasive techniques the portal venous system could be adequately visualized in only 75-80% of cases, despite the injection of various vasodilators [12]. CT angiography shows superior vascular opacification and is an effective technique to demonstrate occlusions of the portal, splenic and superior mesenteric veins; it can also accurately show the various collateral pathways of venous drainage resulting from these occlusions. The post operative status of portocaval and mesocaval shunts can also be accurately shown. CT angiogram with 3-D reconstructions can provide a map of the hepatic venous and intrahepatic portal venous system to allow planning of transjugular intrahepatic porto-systemic shunt procedures, it can also provide sufficient intrahepatic vascular detail to appreciate segmental boundaries based on the Couinaud classification system for effective planning of partial hepatectomies.

Spiral CT angiography is a rapidly evolving technique with vast potential in the field of vascular imaging. It provides a minimally invasive, fast, accurate and economical alternative for imaging the vasculature that was traditionally performed with catheter angiography. However, it remains to be seen whether CT angiography will compete with contrast enhanced MR angiography and surpass it or remain its poor cousin.

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