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Multidetector-row CT angiography of upper- and lower-extremity peripheral arteries

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Abstract With the introduction of multidetector-row CT (MDCT) technology indications for MDCT angiography have expanded to include assessment of the peripheral arteries of the upper and lower extremities. Combined with patient- and scanner-adjusted CT data acquisition and contrast medium application strategies, an accurate and reliable evaluation of the peripheral arteries of the upper and lower extremities is possible. MDCT angiography is cost-effective and accurate for detection of arterial stenosis and occlusion in patients with peripheral arterial disease (PAD). MDCT angiography allows postoperative assessment of peripheral arterial bypass grafts, including bypass graft stenosis and occlusion, as well as presence of aneurysms or arteriovenous fistulas. In addition, MDCT angiography is helpful in particular for visualization of arterial bypass grafts with a complicated extra-anatomical course. Furthermore, pre-operative peripheral vascular mapping can be performed by using MDCT angiography. Finally, due to the integration of MDCT scanners in many trauma centres, MDCT angiography is increasingly being used for assessment of traumatic arterial injuries.
This article gives an overview of technical aspects of peripheral MDCT angiography, including scanning parameters, contrast medium application, image postprocessing and radiation exposure, and summarizes the most frequent acute and non-acute indications of MDCT angiography for assessment of the upper- and lower-extremity peripheral arteries.

Keywords Multidetector-row CT angiography · Peripheral arterial disease · Peripheral arterial bypass graft · Trauma · Vascular mapping

Introduction

Assessment of the upper- and lower-extremity peripheral arteries is routinely performed by contrast-enhanced 3-D magnetic resonance (MR) angiography, Duplex ultrasonography (US) and catheter digital subtraction angiography (DSA). With the introduction of multidetector-row CT (MDCT) technology in 1998 and the continuous development of this technology from 4-detector, 8-detector and 16-detector to 64-detector-row CT scanners within the following years, MDCT angiography of the peripheral arteries now fulfills the prerequisites of an additional new imaging approach before widespread clinical application.

With the worldwide distribution of MDCT scanners and the integration into interdisciplinary emergency rooms of many trauma centres, MDCT angiography can now be offered in a 24-h service in most radiology departments. The fast and easy imaging technique makes MDCT angiography a robust and observer-independent imaging modality for assessment of large anatomical vascular territories at high spatial resolution and constantly high image quality [1]. The fast and non-invasive data acquisition with a radiation exposure about four

Table 1 Scanning parameters for MDCT angiography of upper- and lower-extremity peripheral arteries using different MDCT scanners

	4-detector-row CT[a]	16-detector-row CT[b]	64-detector-row CT[c]
Collimation	4 x 2.5 mm	16 x 0.75	64 x 0.6
Gantry rotation	500 ms	500 ms	500 ms
Tube voltage	120 kV	120 kV	120 kV
Tube current[d]	200 mA	200 mA	200 mA
Table feed	30 mm/s	36 mm/s	69 mm/s
Pitch	1.5	1.5	0.9
Slice thickness	3 mm	0.75	0.6
Increment	1.5 mm	0.4	0.3
Acquisition time[e]	40-47 s	33-39 s	17-20 s

[a] e.g. Sensation 4, [b] Sensation 16, [c] Sensation 64, Siemens, Forchheim, Germany, [d] Tube current can be reduced by using automated tube current modulation (ATCM), [e] Acquisition time is calculated for a scanning range of 1.2 – 1.4 m

times smaller compared to catheter DSA has significantly improved patient acceptance of MDCT angiography [2–4]. Finally, many prospective clinical studies have proven a high diagnostic accuracy of MDCT angiography compared to catheter DSA, MR angiography and Duplex US for assessment of the aorto-iliac and peripheral arteries [3–9]. Therefore, MDCT angiography has replaced invasive diagnostic DSA in many radiology departments, and is now accepted as an alternative to MR angiography and Duplex US by most referring clinicians.

This article addresses technical aspects of peripheral MDCT angiography and gives an overview of the most frequent acute and non-acute indications of MDCT angiography for assessment of the upper- and lower-extremity peripheral arteries.

MDCT scanning technique

The major advantages of MDCT angiography compared to single-detector-row CT (SDCT) angiography include faster scanning, coverage of a larger anatomical range and thinner section thickness with higher spatial resolution along the z-axis. To fully exploit these advantages, close attention to optimized CT data acquisition and contrast medium application protocols for MDCT angiography is required.

The scanning parameters for MDCT angiography depend on the abilities of the MDCT scanner and the anatomical vascular territory under consideration. For scanning the lower-extremity peripheral arteries, the patient is placed with his feet entering the gantry first. For assessment of the upper-extremity arteries the affected extremity is positioned beside the body and the other arm (through which contrast material is injected) is elevated above the head.

In general, the thinnest possible collimation and a 25-50% reconstruction overlap should be applied, resulting in an (almost) isotropic CT dataset. A pitch of 1.5 is usually used. However, to avoid running ahead of the contrast bolus with a table feed exceeding 50 mm/s [10], the pitch is reduced using a 64-detector-row CT scanner (Table 1). For optimal in-plane resolution of peripheral MDCT angiography, two practical details should be noted: it is recommended to use tape and fix the patient's knees and feet together, since without tape the feet tend to fall away from one another, which results in a larger field-of-view in the reconstruction process to fully include the proximal anterior tibial arteries. In addition, transverse sections are reconstructed for each extremity separately with a field-of-view of about 25 cm. Combined with a 512 x 512 matrix, this reconstruction results in a true voxel size of 0.18 and 0.14 mm^3, respectively, for 16-detector-row CT (slice thickness, 0.75 mm) and 64-detector-row CT angiography (slice thickness, 0.6 mm).

Contrast medium application

Optimized contrast medium injection strategies are of paramount importance for MDCT angiography, in particular when fast CT data acquisition is performed with 16-detector and 64-detector-row CT scanners. In daily routine the following parameters may be considered for optimal intra-arterial contrast enhancement: determination of scanning delay, iodine concentration of contrast medium and contrast medium injection rate, as well as saline flushing of the injection veins.

Due to the inter-individual wide range of the time from the intravenous injection site to the arterial site of interest, in particular in patients with cardiac disease and obstructive and dilatative arteriopathy, a fixed scanning delay cannot be recommended for MDCT angiography of the peripheral arteries. The patient's contrast medium transit time should be obtained based on test bolus or bolus-tracking techniques. The test bolus technique measures the time to peak intra-arterial enhancement in a region of interest placed in a reference vessel after injection of a test bolus of 15–20 ml non-ionic iodinated contrast medium. The bolus-tracking technique includes an automatic initiation of the MDCT scan after reaching a preset contrast enhancement level (usually 100-120 HU) in a region of interest placed in a reference vessel and after application of the total amount of non-ionic iodinated contrast medium.

A practical approach to contrast medium injection strategies is to adjust the injection duration to the scanning duration. Since intra-arterial opacification in MDCT angiography is proportional to the iodine administration rate, both the iodine concentration of contrast medium and the contrast medium injection rate need to be adjusted to the scanning duration. In fast MDCT angiography scanning (e.g. short anatomical range only) a high iodine administration rate can be obtained either by increasing the injection rate up to 6 ml/s with a standard iodine concentration (300 mg I/ml) or, more conveniently, due to the limited size of the intravenous needle, by using a higher concentrated contrast medium (e.g. 370 mg I/ml) with lower flow rates between 3 and 4 ml/s [10]. In longer-lasting MDCT angiography scanning (e.g. aorto-iliac and peripheral arteries) a uniform and prolonged enhancement can additionally be achieved by using a biphasic injection protocol with an initial short high-rate injection followed by a longer-lasting low-rate injection [11]. However, optimal contrast medium application can be challenging when using fast 64-detector-row CT scanners even for assessment of large anatomical ranges such as the aorto-iliac and peripheral arteries, since the CT data acquisition may outpace the contrast bolus, with consequent reduced opacification of distal peripheral arteries. A practical approach when using bolus-tracking techniques is to add an additional delay time after reaching the preset attenuation level and before automatic initiation of the MDCT angiographic scan. This additional delay time (in general between 10 and 20 s for lower-extremity peripheral angiographies) varies according to the amount and application rate of the contrast medium as well as the scanning parameters, the scanning range and the contrast medium transit time in different patients.

Flushing the injection veins with 30-50 ml saline by using an automatic double injector device prolongs and slightly increases arterial enhancement and reduces the overall amount of contrast medium needed [12].

Since gadolinium shows even higher photon attenuation than iodine, a small subset of patients with contraindications to both MR imaging and iodinated contrast medium may benefit from gadolinium-enhanced MDCT imaging. In a preliminary prospective study with seven patients Chicoskie et al. [13] demonstrated diagnostic enhancement and good image quality of the abdominal aorta and its major branches on MDCT angiography images following intravenous application of 40 ml gadopentetate dimeglumine at a flow rate of 4 ml/s. However, further studies are needed to prove gadolinium-enhanced MDCT angiography accurate for assessment of vascular pathologies of the aorta and peripheral arteries.

Reduction of radiation exposure

For reduction of radiation exposure during MDCT scanning, techniques of automated tube current modulation (ATCM) have been implemented on most modern MDCT scanners. ATCM allows automatic adjustment of the tube current in the x-y plane (angular modulation), along the z-axis (z-axis modulation), or along all three planes according to the size and attenuation characteristics of the body part of the patient being scanned. Initial studies have shown a 20–60% dose reduction, depending on the anatomical region and patient habitus, without significant reduction of image quality [14, 15]. By reducing the tube voltage from 120 to 100 kV, Wintersperger et al. [16] showed a mean reduction of radiation exposure of about 37% in aorto-iliac MDCT angiography, without significant change in image quality.

Postprocessing and image analysis

To improve postprocessing image quality, positive oral contrast materials should be avoided during MDCT angiography data acquisition.

High-performance workstations with 3-D capabilities are needed to quickly load and process the large data of MDCT angiographies. We recommend the analysis of transverse images combined with curved reconstructions of vessels with a tortuous course as the first step of image analysis. By scrolling all images on the workstation, this approach allows a rapid diagnosis of arterial stenosis and occlusion and assessment of arterial wall pathology as well as presence of intraluminal thrombus. Using a wide bone window setting (e.g. W/L = 2000/500) is of paramount importance when assessing the transverse and curved MDCT angiography images. In particular, in the presence of extensive arterial wall calcification, arterial stenosis may be overestimated due to a "blooming artefact" of arterial wall calcium when standard window settings (e.g. W/L = 500/150) are applied. Vascular pathologies may be documented and demonstrated to the referring clinician by using multiplanar reconstructions (MPR), maximum intensity projections (MIP) and volume-rendered reconstructions (VR). While MIP and VR provide an angiographic view and information about the extent and location of arterial wall calcifications (which are important information before surgery is performed), presence of calcification makes evaluation of vessel stenosis impossible based on MIP and VR.

For better spatial resolution of MIP and VR images on the workstations it is recommended to separate the arterial tree of the lower extremity into three segments since most CT workstations automatically rescale images to a 512 x 512 matrix. Promising results of efficient image analysis have been demonstrated by using pro-

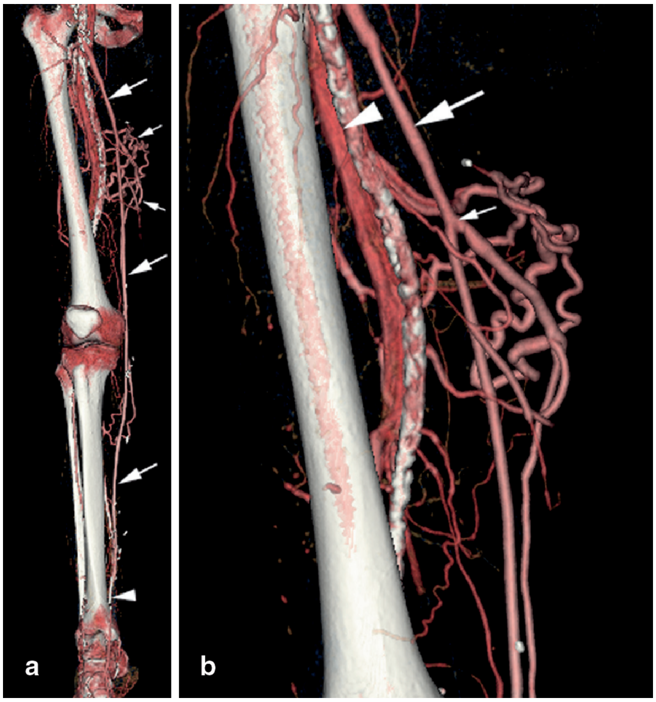

Fig. 1 **a** Anteroposterior volume-rendered MDCT angiography image of a 51-year-old woman with an autologous in situ saphenous vein femorocrural bypass graft (*large arrows*) grafted onto the posterior tibial artery (*arrowhead*). Vascular convolute (*small arrows*) along the course of the bypass graft can be seen. **b** Detailed anteroposterior volume-rendered image in the same patient demonstrates arteriovenous fistula (*small arrow*) which originates from the in situ saphenous vein bypass graft (*large arrow*) feeding the vascular convolute. Note early enhancement of the superficial femoral vein (*arrowhead*)

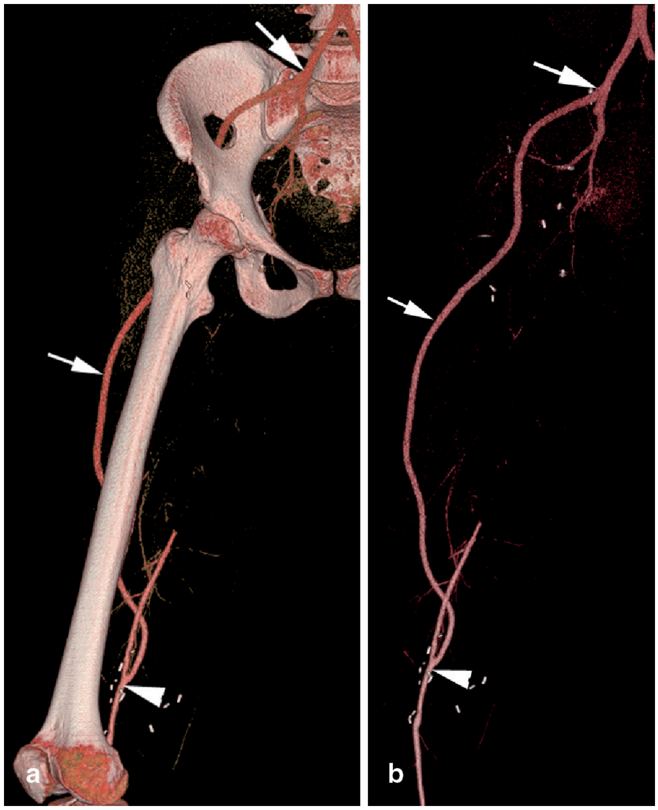

Fig. 2 32-year-old woman with transiliac extra-anatomic iliacopopliteal xenograft. Anteroposterior volume-rendered MDCT angiography image before **a** and after **b** segmentation of bony structures demonstrates patency of arterial bypass graft with proximal anastomosis (*large arrow*), bypass course (*small arrow*) and distal anastomosis (*arrowhead*) grafted onto popliteal artery

grammes for automated vessel tracking and calculation of orthonormal arterial diameters [17].

Clinical applications

Recent studies have proven the high diagnostic accuracy of 4-detector-row CT angiography in the assessment of the aorto-iliac and lower-extremity arteries in patients with peripheral arterial disease (PAD). By using a slice thickness between 1.25 and 5 mm, sensitivities and specificities between 91 and 99% have been demonstrated [5–9]. However, due to the still limited spatial resolution along the z-axis, evaluation of vessels with small luminal diameter is still challenging for 4-detector-row CT angiography. In the study of Ofer et al. [5] 14 of the 22 (64%) clinically important mismatches between catheter DSA and 4-detector-row CT angiography were located in the small renal and peripheral arteries of the calves. All of the 22 segments which could not be evaluated by 4-detector-row CT angiography occurred in the small peripheral arteries of the calves in the study of Martin et al. [6]. However, for 16-detector row CT angiography, excellent sensitivities and specificities of 96 and 97%, respectively, for grading stenosis of even small popliteocrural arteries have been demonstrated due to improved spatial resolution [4].

An advantage of MDCT angiography is the peripheral venous compared to the central aortic administration of contrast material in catheter DSA, allowing better opacification of collateral circulation and thus of arteries distal to an occlusion site. Ten of 480 arterial segments (2%) assessable on MDCT angiograms could not be evaluated by catheter DSA in the study of Ota et al. [8]. In the study of Martin et al. [6] 91 of 105 arterial segments (86.7%) that could not be evaluated by catheter DSA were diagnostic on MDCT angiograms.

Additionally, in a recent study a possible new imaging modality has been found to be cost-effective compared to catheter DSA in patients with intermittent claudication, if the costs of the new imaging modality were 300 US dollars or less, both angioplasty and bypass surgery were considered as treatment options, and the sensitivity of the new imaging modality was higher than 94% [18].

Fig. 3 50-year-old man with severe dislocated proximal tibial fracture after motor vehicle accident, who underwent MDCT angiography for exclusion of traumatic peripheral arterial injury. Posterior volume-rendered MDCT angiography image demonstrates normal enhancement of the popliteal and distal run-off arteries without evidence of traumatic vascular injury

With 16-detector-row CT angiography, a sensitivity higher than 94% has been demonstrated for peripheral angiography, including the aorto-iliac, the femoral as well as the popliteocrural region [4]. In patients with PAD and contra-indications for MR imaging 16- or 64-detector-row CT angiography can be recommended as an alternative imaging modality for assessment of the peripheral arteries including the distal arteries of the calves.

Postoperative surveillance of peripheral arterial bypass grafts is considered to be important, since as many as 30% of patients develop graft-related complications within the first 2 years after surgery. Due to the good availability and low cost Duplex US is considered to be the primary imaging modality for use in postoperative graft surveillance. Many vascular surgeons, however, still consider catheter DSA to be a mandatory procedure before performance of a surgical or percutaneous intervention for a bypass graft stenosis depicted with Duplex US [19]. In a prospective study with 65 patients and 85 peripheral arterial bypass grafts, it has been demonstrated that 4-detector-row CT angiography is feasible, accurate and reliable in the assessment of peripheral arterial bypass grafts and detection of graft-related complications, including stenosis, aneurysmal changes and arteriovenous fistulas (Fig. 1) [3]. Because of its non-invasive nature, MDCT angiography may replace catheter DSA as a technique to be used after performance of Duplex US to help physicians plan further treatment of peripheral arterial bypass grafts. In addition, MDCT angiography is in particular helpful for assessment of the integrity of the entire course of extra-anatomical arterial bypass grafts with a complicated anatomy which may be difficult to evaluate with Duplex US (Fig. 2).

MDCT angiography can also be used as an alternative to Duplex US and catheter DSA for pre-operative arterial vessel mapping of the upper and lower extremities. MDCT angiography is accurate for arterial mapping before free flap reconstruction and complex extremity reconstructions in the upper- and lower-extremity arteries [20, 21]. In a study with 14 patients, Bogdan et al. [21] demonstrated a 100% agreement between MDCT angiography and intra-operative findings regarding arterial anatomy in patients with complex upper-extremity reconstructions. Pre-operative findings from MDCT angiography changed surgical approach in two of the 14 patients. In 10 patients who underwent microsurgical reconstruction in the lower extremity, head and neck, and upper extremity, all relevant information needed for surgical planning was obtained on the MDCT angiography images [20]. In addition, in this study MDCT angiography was more cost-effective compared to catheter DSA for pre-operative arterial vessel mapping [20].

MDCT angiography is also an accurate and safe imaging modality for pre-operative assessment of the radial artery, hand circulation and anatomical arterial variants. In all 16 consecutive patients who were scheduled for coronary artery bypass grafting, mapping of the radial artery and hand circulation was successful with MDCT angiography [22]. In addition, two anatomical variants were seen on MDCT angiography, including a persistent median artery in one patient and a high bifurcation of the radial artery in another [22].

Indications for vascular imaging in the trauma setting include abnormal distal pulses, signs of haemorrhage, limb ischemia, injury of an adjacent structure (nerve injury, severe skeletal injury), or a penetrating injury close to a major vessel. For SDCT angiography, Soto et al. [23] demonstrated a high sensitivity and specificity of 95.1 and 98.7%, respectively, for the detection of traumatic arterial injuries, including partial and complete occlusion, pseudoaneurysm formation, as well as presence of arteriovenous fistula or intimal flap. However, due to the limited anatomical coverage of SDCT angiography, only injuries limited to the proximal upper and lower extremities were included in this study. With the integration of MDCT scanners into trauma rooms, an increasing number of patients are being evaluated by MDCT angiography for visualization or exclusion of traumatic vascular injuries (Fig. 3). In a preliminary prospective study of 45 patients after trauma, Mallouhi et al. [24] demonstrated a sensitivity and specificity of 96 and 88%, respectively, in the detection of arterial traumatic injuries of both proximal and distal upper and lower extremities compared to the intra-operative findings. Due to the good availability and fast scanning capabilities, MDCT angiography may replace diagnostic catheter DSA in the trauma setting for assessment of traumatic arterial injuries.

Summary

Due to faster scanning, coverage of a larger anatomical range and thinner section thickness with higher spatial resolution along the z-axis compared to SDCT imaging, indications for MDCT angiography have broadened to include the peripheral arteries of the upper and lower extremities. Close attention to optimized CT data acquisition and contrast medium application protocols are of paramount importance when performing MDCT angiography of the peripheral arteries. MDCT angiography has been demonstrated to be accurate and reliable for assessment of peripheral arteries and bypass grafts in patients with PAD. In addition, MDCT angiography is useful for pre-operative arterial vascular mapping of the upper- and lower-extremity arteries. Widespread availability combined with fast and robust imaging makes MDCT angiography the imaging modality of choice for assessment of traumatic arterial injuries in an emergency situation. MDCT angiography is limited in patients with diabetes or patients on hemodialysis and extensive arterial wall calcification in particular for evaluation of small arteries of the calves. Further effort is needed to reduce radiation exposure during MDCT angiography.

References

1. Rubin GD, Shiau MC, Leung AN, Kee ST, Logan LJ, Sofilos MC (2000) Aorta and iliac arteries: single versus multiple detector-row helical CT angiography. Radiology 215:670–676
2. Rubin GD, Schmidt AJ, Logan LJ, Sofilos MC (2001) Multi-detector row CT angiography of lower extremity arterial inflow and runoff: initial experience. Radiology 221:146–158
3. Willmann JK, Mayer D, Banyai M, Desbiolles LM, Verdun FR, Seifert B, Marincek B, Weishaupt D (2003) Evaluation of peripheral arterial bypass grafts with multi-detector row CT angiography: comparison with duplex US and digital subtraction angiography. Radiology 229:465–474
4. Willmann JK, Baumert T, Schertler T, Wildermuth S, Pfammatter T, Verdun FR, Seifert B, Marincek B, Böhm T (2005) Aortoiliac and lower extremity arteries assessed with 16-detector row CT angiography: prospective comparison with digital subtraction angiography. Radiology 236:1083–1093
5. Ofer A, Nitecki SS, Linn S, Epelman M, Fischer D, Karram T, Litmanovich D, Schwartz H, Hoffman A, Engel A (2003) Multidetector CT angiography of peripheral vascular disease: a prospective comparison with intraarterial digital subtraction angiography. AJR 180:719–724
6. Martin ML, Tay KH, Flak B, Fry PD, Doyle DL, Taylor DC, Hsiang YN, Machan LS (2003) Multidetector CT angiography of the aortoiliac system and lower extremities: a prospective comparison with digital subtraction angiography. AJR 180:1085–1091
7. Willmann JK, Wildermuth S, Pfammatter T, Roos JE, Seifert B, Hilfiker PR, Marincek B, Weishaupt D (2003) Aortoiliac and renal arteries: prospective intraindividual comparison of contrast-enhanced three-dimensional MR angiography and multi-detector row CT angiography. Radiology 226:798–811
8. Ota H, Takase K, Igarashi K, Chiba Y, Haga K, Saito H, Takahashi S (2004) MDCT compared with digital subtraction angiography for assessment of lower extremity arterial occlusive disease: importance of reviewing cross-sectional images. AJR 182:201–209
9. Catalano C, Fraioli F, Laghi A, Napoli A, Bezzi M, Pediconi F, Danti M, Nofroni I, Passariello R (2004) Infrarenal aortic and lower-extremity arterial disease: diagnostic performance of multi-detector row CT angiography. Radiology 231:555–563
10. Fleischmann D (2003) High-concentration contrast media in MDCT angiography: principles and rationale. Eur Radiol 13[Suppl 3]:N39–N43
11. Fleischmann D, Rubin GD, Bankier AA, Hittmair K (2000) Improved uniformity of aortic enhancement with customized contrast medium injection protocols at CT angiography. Radiology 214:363–371
12. Schoellnast H, Tillich M, Deutschmann MJ, Deutschmann HA, Schaffler GJ, Portugaller HR (2004) Aortoiliac enhancement during computed tomography angiography with reduced contrast material dose and saline solution flush: influence on magnitude and uniformity of the contrast column. Invest Radiol 39:20–26
13. Chicoskie C, Tello R (2005) Gadolinium-enhanced MDCT angiography of the abdomen: feasibility and limitations. AJR 184:1821–1828
14. Suess C, Chen X (2002) Dose optimization in pediatric CT: current technology and future innovations. Pediatr Radiol 32:729–734; discussion 751–724
15. Greess H, Lutze J, Nomayr A, Wolf H, Hothorn T, Kalender WA, Bautz W (2004) Dose reduction in subsecond multislice spiral CT examination of children by online tube current modulation. Eur Radiol 14:995–999
16. Wintersperger B, Jakobs T, Herzog P, Schaller S, Nikolaou K, Suess C, Weber C, Reiser M, Becker C (2005) Aorto-iliac multidetector-row CT angiography with low kV settings: improved vessel enhancement and simultaneous reduction of radiation dose. Eur Radiol 15:334–341

17. Lutz AM, Willmann JK, Pfammatter T, Lachat M, Wildermuth S, Marincek B, Weishaupt D (2003) Evaluation of aortoiliac aneurysm before endovascular repair: comparison of contrast-enhanced magnetic resonance angiography with multidetector row computed tomographic angiography with an automated analysis software tool. J Vasc Surg 37:619–627
18. Visser K, Kock MC, Kuntz KM, Donaldson MC, Gazelle GS, Hunink MG (2003) Cost-effectiveness targets for multi-detector row CT angiography in the work-up of patients with intermittent claudication. Radiology 227:647–656
19. Landry GJ, Moneta GL, Taylor LM, Jr., McLafferty RB, Edwards JM, Yeager RA, Porter JM (1999) Duplex scanning alone is not sufficient imaging before secondary procedures after lower extremity reversed vein bypass graft. J Vasc Surg 29:270-280; discussion 280–271
20. Klein MB, Karanas YL, Chow LC, Rubin GD, Chang J (2003) Early experience with computed tomographic angiography in microsurgical reconstruction. Plast Reconstr Surg 112:498–503
21. Bogdan MA, Klein MB, Rubin GD, McAdams TR, Chang J (2004) CT angiography in complex upper extremity reconstruction. J Hand Surg [Br] 29:465–469
22. Dogan OF, Karcaaltincaba M, Duman U, Akata D, Besim A, Boke E (2005) Assessment of the radial artery and hand circulation by computed tomography angiography: a pilot study. Heart Surg Forum 8:E28–E33
23. Soto JA, Munera F, Morales C, Lopera JE, Holguin D, Guarin O, Castrillon G, Sanabria A, Garcia G (2001) Focal arterial injuries of the proximal extremities: helical CT arteriography as the initial method of diagnosis. Radiology 218:188–194
24. Mallouhi A, Tauscher T, Lutz M, Perkmann R, Jaschke WR, Rieger M. (2003) Traumartic arterial injuries of the extremities: initial evaluation with multi-detector row CT angiography. Radiology P 677