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ORIGINAL ARTICLE

Ulf H. Beier · Eunice John · Adisorn Lumpaopong · Jennifer G. Co · Vladimir Jelnin · Enrico Benedetti · Giuliano Testa · Ramona Bottke · Bruce I. Sharon · Carlos E. Ruiz

Electron-beam CT as a diagnostic modality in pediatric nephrology and renal transplant surgery

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Abstract Electron-beam computed tomography is an imaging technology with a variety of medical applications, primarily in cardiology due to its sub-second acquisition time enabling visualization of a beating heart. Recently, this technique has also been introduced into other fields because of lower radiation exposure compared to traditional computed tomography, as well as the strengths of post-procedural three-dimensional visualization. This report evaluates electron-beam computed tomography as a diagnostic modality in pediatric nephrology patients. Seven patients reflecting typical clinical scenarios in pediatric nephrology were reviewed with regard to the value of electron-beam computed tomography and its contribution to the diagnostic workup. Electron-beam computed tomography is noninvasive and allows three-dimensional post-processing, enabling highly accurate images while requiring less radiation and acquisition time. It is very useful for clinical questions that require a detailed description of vascular and renal anatomy.

U. H. Beier (✉) · E. John · A. Lumpaopong · J. G. Co · R. Bottke
Department of Pediatrics, University of Illinois at Chicago,
840 South Wood Street, Room 1438 CSB,
Chicago, IL 60612-7324, USA
e-mail: ubeier1@uic.edu
Tel.: +1-312-4133803
Fax: +1-312-4130243

V. Jelnin · C. E. Ruiz
Division of Pediatric Cardiology, Department of Pediatrics,
University of Illinois at Chicago,
840 South Wood Street,
Chicago, IL 60612, USA

E. Benedetti · G. Testa
Division of Transplantation, Department of Surgery,
University of Illinois at Chicago,
840 South Wood Street,
Chicago, IL 60612, USA

B. I. Sharon
Division of Pediatric Hematology and Oncology,
Department of Pediatrics, University of Illinois at Chicago,
840 South Wood Street,
Chicago, IL 60612, USA

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Abbreviations CT: Computed tomography · EBCT: Electron-beam computed tomography

Introduction

The past 50 years have brought remarkable advances in the imaging techniques available to pediatric nephrologists to make accurate diagnoses and to visualize underlying pathology and treatment effects as well as to minimize harm to the patient from diagnostic interventions [1, 2]. Although ultrasound, mercaptoacetyltriglycine nuclear scans and conventional multislice computed tomography as well as angiography are well established, advances in diagnostic imaging continue to be a major field of interest in pediatric nephrology. Electron-beam computed tomography (EBCT) is an imaging modality with short acquisition time and relatively low radiation exposure. While EBCT has been primarily utilized in the field of cardiology, several groups have recently investigated its use in other specialties [3, 4]. We report seven cases reflecting a variety of clinical scenarios in pediatric nephrology, in order to scrutinize advantages and limitations of this technology in these patients.

Methods

The EBCT studies presented in this work were done using a C-150 EBT scanner (GE-Imatron, South San Francisco, CA) using the single-slice volume mode (3 mm). Table increments used were 2 mm between consecutive acquisitions. Three-dimensional reconstruction of the digital communication in medicine image files was achieved using sharp reconstruction kernel. The position of patients was head-first in supine position on the scanner table with the table in neutral position. Image enhancement was

obtained by injection of Iodixanol-320 contrast (Visipaque, Amersham Health, Cork, Ireland) via either a peripheral or central vein at up to 3 cc/kg.

Case reports

Case 1: congenital dysplastic kidney

An 18-year-old male presented with hypertension and end organ damage. During initial evaluation, an ultrasound suggested a renal artery stenosis. However, an EBCT delineated one hypertrophic kidney with two renal arteries, and absent blood flow to the opposite kidney, which was dysplastic (Fig. 1a). These findings were later confirmed by angiography.

Case 2: renal artery stenosis

A 3-year-old male presented with hypertension and obesity. The initial workup was significant for a high renin of 10.1 pg/ml (2.3937 pmol/l), which led to a suspicion of renal artery stenosis. Ultrasound studies failed to reveal any evidence of renal artery narrowing, but an EBCT finally established the diagnosis of right renal artery stenosis (Fig. 1b,c).

Case 3: hydronephrosis after renal transplant

A 12-year-old male with dysplastic kidneys, end-stage renal disease, and rejection of a cadaveric renal transplant developed ascites and fever of 40°C shortly after his second renal transplant. The initial evaluation revealed an increase in the serum creatinine to 4.0 mg/dl (353.6 mol/l). Mercaptoacetyltriglycine radionucleotide scan and ultrasound were suggestive of left-side hydronephrosis of the newly transplanted kidney, and the possibility of abscess

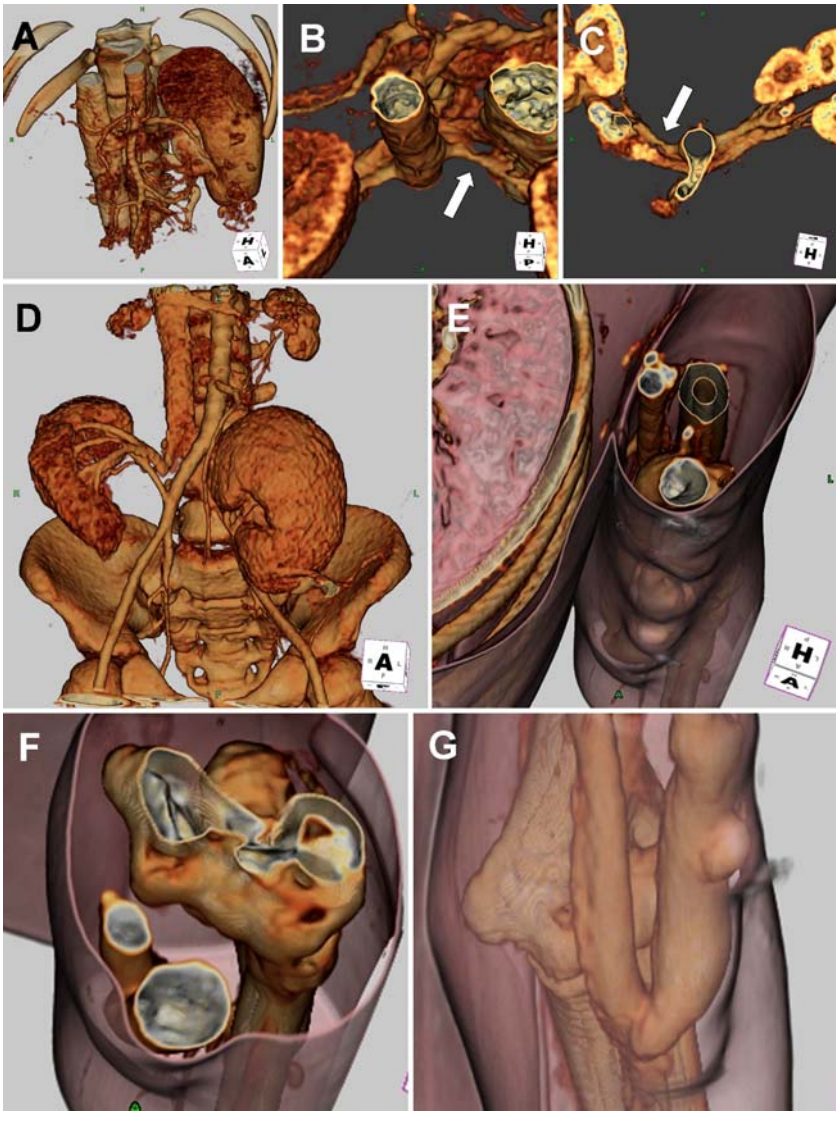

Fig. 1a–g Electron-beam computed tomography scans after three-dimensional processing. **a** Two renal arteries supply the left kidney, which is hyperplastic. **b**, **c** Filling defect in the right renal artery suggestive of a stenosis (*white arrows*). **d** Status post second cadaveric renal transplant. The most recent transplant (left abdomen) appears with mild hydronephrosis, the anastomoses are intact. The left native kidney is visualized with hydronephrosis. **e–g** Dilation of the basilic vein visualized with cross sections of the left upper arm. The anastomosis site appears intact in a close-up view

and anastomotic leak was entertained. A subsequent EBCT did not reveal any leak from the ureterovesicular junction and the vascular anastomoses were intact. Furthermore, significant hydronephrosis was only present in the native, not in the newly transplanted kidney (Fig. 1d).

Case 4: congestive cardiac failure after arterovenous fistula

A 12-year-old female with end-stage renal disease secondary to sclerosing glomerulonephritis on hemodialysis presented with shortness of breath. Initial workup revealed congestive cardiac failure. She received a cadaveric renal transplant, but her congestive heart failure continued to get worse, and she developed pulmonary edema. An EBCT demonstrated a distended basilica vein secondary to an enlarged arteriovenous fistula. The fistula was ligated based on the findings from the EBCT, and the patient subsequently recovered from the congestive heart failure (Fig. 1e–g).

Case 5: renal vein and inferior vena cava thrombosis

A 17-year-old female with history of multiple medical problems including systemic lupus erythematosus, lupus nephritis, end-stage renal disease and a previously thrombosed inferior vena cava status post Wallstent placement presented with an acute rise in creatinine level. An EBCT was done to rule out renal vein thrombosis in conjunction with the occlusion of the inferior vena cava. The EBCT findings showed a complete thrombosis of the inferior vena cava from the middle of the Wallstent to the level of the femoral veins (Fig. 1f). The renal arteries appeared patent. In addition, EBCT demonstrated the formation of an extensive network of collaterals (Fig. 2a).

Case 6: arteriovenous fistula bleeding

A 17-year-old female with history of cystinosis and two cadaveric renal transplants presented with sudden swelling and pain at the site of her arteriovenous fistula on her left arm. She had previously been admitted for edema on the same site and was diagnosed with pseudoaneurysm of the

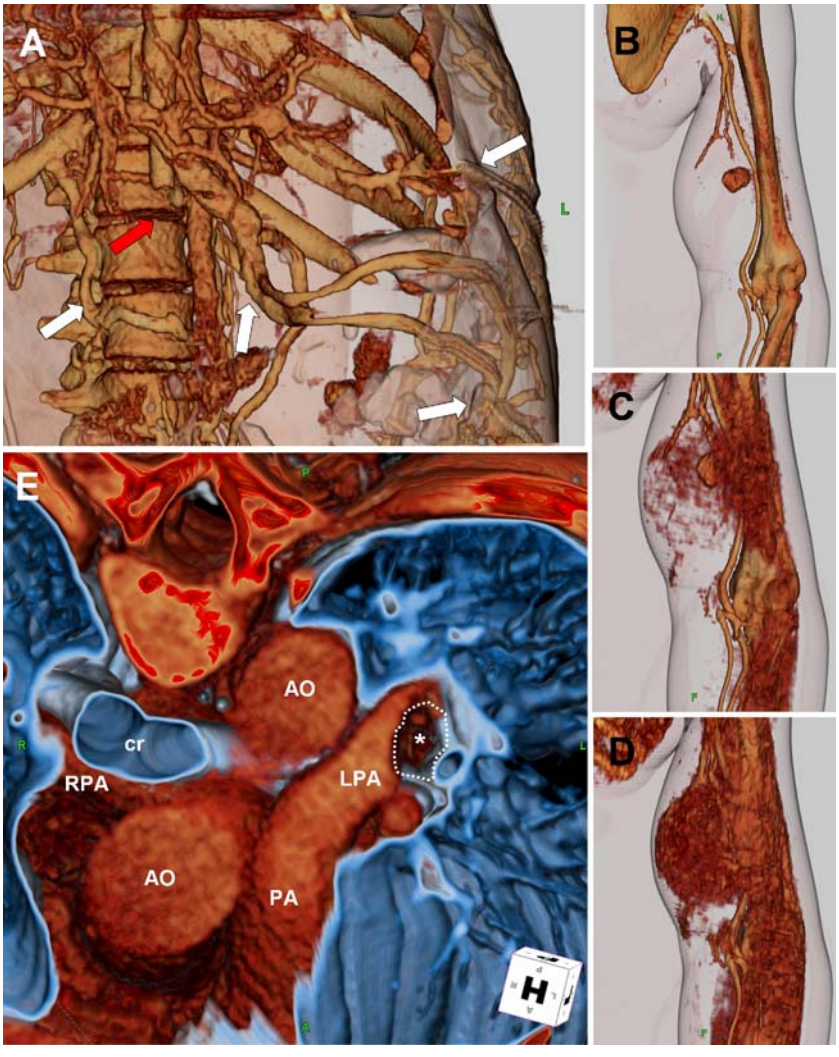

Fig. 2 **a** The inferior vena cava is blocked and cannot be visualized below L1 (*red arrow*). Several anastomoses have formed (*white arrows*), including prominent vertebral veins, caput medusae, a re-canalized umbilical vein, and a dilated vena epigastrica superior. **b–d** Hemorrhage of an arteriovenous fistula in the left upper arm, displayed with increasing signal sensitivity, which delineates a hematoma in the distal humeral area. **e** Transthoracic cross section. Blood vessel signal is displayed in *red*, lung tissue signal in *blue*. Extravascular mass impinging the left pulmonary artery as well as the lung tissue (*dotted line*, *asterisk*). *cr* Carina, *PA* pulmonary artery, *RPA* right pulmonary artery, *LPA* left pulmonary artery, *AO* aorta

basilic vein. However, there were conflicting findings from the ultrasound, which showed that the pseudoaneurysm was emanating from the artery, and the arteriogram, which showed that it was originating from the vein. Intraoperatively, no communication between the venous system and the artery was found. Per the surgical notes, it appeared that there was still pulsatile nature to the pseudoaneurysm. Intraoperative ultrasound demonstrated no flow in the fistula, and the fistula vein was ligated. On her second admission for acute painful swelling of the arteriovenous fistula site, an EBCT was performed, which revealed hematoma formation and pseudoaneurysm of the left brachial artery with no active flow into the cavity. This aided the surgeons to delineate the anatomy prior to surgical drainage of the hematoma (Fig. 2b–d).

Case 7: thoracic metastasis of Wilms tumor

An 8-year-old male presented with weight loss and an abdominal mass, which was eventually diagnosed as Wilms tumor. Upon staging of the tumor disease, a suspicious mass was noted on thoracic CT, and a subsequent EBCT with three-dimensional visualization revealed an extravascular mass pressing on bronchi as well as on the left pulmonary artery. The EBCT reading was suggestive of metastatic disease in the lung (Fig. 2e). A tissue biopsy was not attempted because of concern of the risk of pulmonary hemorrhage.

Discussion

The cases reported in this work show that EBCT is a useful diagnostic modality especially in those patients who require accurate imaging of the renal anatomy as well as the vasculature. Previously, Tepe at al. reported EBCT technology as helpful in assessing the renal arteries for the presence of variants or stenosis before surgery [5]. In addition, this technology has been applied to assess artherosclerosis in patients on chronic hemodialysis [6, 7]. Talisetti et al. reported EBCT imaging in two surgical pediatric patients, one involving a two-kidney en-bloc transplant [4]. This work is the first report on a broad variety of pediatric nephrologic cases that reflect the potential to apply this technology to this clinical population.

Table 1 Costs of renal imaging procedures

Procedure	Price (in USD)
Renal ultrasound[a]	521.00
Mercaptoacetyltriglycine scan[a]	1,133.00
Abdominal CT[a]	1,026.00
Abdominal EBCT[b]	800.00
Abdominal MRI[a]	1,652.00

[a]Costs of renal imaging procedures at the University of Illinois at Chicago Medical Center as of July 2005. The figures do not include expenses for interpretation or sedation

[b]Cost of abdominal EBCT at the University of Illinois as by Heart Check America, Los Angeles, CA

Electron-beam CT applications

Despite advances in renal ultrasound, magnetic resonance imaging, and computed tomography, digital subtraction angiography remains the reference standard for the evaluation of renal artery stenosis [8]. Computed tomographic angiography and magnetic resonance angiography are not reproducible or sensitive enough to rule out renal artery stenosis, especially in hypertensive patients, which makes them unlikely to challenge the leading role of digital subtraction angiography [9]. Nevertheless, digital subtraction angiography is invasive and can lead to complications including pain, hematoma, and abscesses, which limit its application [10]. With regard to noninvasiveness and cost-effectiveness, ultrasound has been investigated and has been shown to be successful especially in predicting functional recovery prior to a corrective intervention [11]. However, the current literature shows that renal ultrasound is not sensitive enough to detect stenotic changes in the renal arteries reliably enough, which is of concern considering the wide range of potential sequelae of a missed diagnosis [12]. The images reconstructed from EBCT data allow a sound display of the vasculature, which is supported by a more rapid image-capturing sequence compared to normal CT, leading to fewer motion artifacts. In comparison to MRI, CT-based techniques have the advantage of better spatial resolution, which enables improved three-dimensional reconstruction [13]. Therefore, EBCT could offer an alternative or at least an addition to more invasive digital subtractive angiography in the future.

In addition to the evaluation of renal artery stenosis, transplant surgery could offer another field of potential EBCT applications. Renal transplantations are performed at an increasing frequency in pediatric patients due to improved outcome [14]. Insufficient vascular supply of the renal transplant is one of the leading causes of graft failure, and therefore the accurate diagnostic assessment of the graft vasculature, both immediately after the procedure as well as long term has become an important field. Renal artery stenosis and renal vein thrombosis are the two most common vascular complications of renal transplantation [15]. Ultrasound plays a major role in the imaging of these patients, especially for the assessment of blood flow and the visualization of the graft tissue, but also in detecting graft dysfunction and peritransplant fluid collection [16, 17]. Renal ultrasound is, among the imaging modalities mentioned in this report, by far the cheapest procedure, with CT and MRI requiring double and triple the expenses, respectively (Table 1). The cost of an abdominal EBCT is lower than that of a CT; however, they are likely to remain higher than ultrasound.

In our cases, EBCT was suggested as more accurate for assessing patency of the renal blood vessels and the presence of hydronephrosis, and could extend the diag-

nostic panoply available for renal transplant patients, especially in those cases that require a distinct visualization of the vascular supply.

Another new area for EBCT could be in the imaging of hemodialysis access sites in patients with end-stage renal disease. Hemodialysis and related procedures require a reliable vascular access, and close monitoring has been shown to prolong the endurance for both fistulas and grafts [18]. Goldstein et al. showed that ultrasound screening combined with referral for angioplasty could lead to a significant decrease in hospitalization for vascular access thrombosis, which is the most common complication [19]. Today, color Doppler sonography is regarded as the reference method for diagnosing vascular access dysfunctions [20, 21]. Nevertheless, we do see advantages of the EBCT in this field over ultrasound, especially in the evaluation of nonthrombotic complications of an access site, e.g., bleeding, stenosis, and pseudoaneurysms. In case 6, EBCT was very useful especially in the preoperative planning secondary to its fine tissue delineation and allowed an optimized pre-surgical assessment of the access site.

Finally, our cases also support an oncologic application of the EBCT: in plain contrast CT or angiography, the causality of vascular filling defects is hard to assess. In case 7, EBCT demonstrated a precise overview of the vascular and pulmonary anatomy, and therefore showed that the filling defect was extending into both the left pulmonary artery as well as the bronchial tree, which made a pulmonary embolism less likely, and strengthened the suspicion of a metastasis of the Wilms tumor compressing both structures.

Radiation exposure and sedation

Ionizing radiation exposure and its associated morbidities due to diagnostic procedures are a major concern in contemporary medicine [22]. Children are especially vulnerable to the adverse effects of radiation, including radiation-induced cancers [23]. One of the advantages of EBCT over a conventional computed tomography is the lower radiation exposure, which has been reported as six to ten times lower [24, 25]. In addition, EBCT can provide a rapid imaging evaluation with minimal need for sedation as opposed to conventional CT; EBCT therefore carries fewer associated risks such as hypothermia, respiratory suppression and aspiration [26].

Conclusion

In summary, EBCT has been shown to be an efficient and safe imaging modality with numerous applications in pediatric nephrology. The cases presented could help establish EBCT as an imaging modality, especially for those clinical questions that require evaluation of the vascular system.

References

1. O'Neill W, Baumgarten DA (2003) Imaging. Am J Kidney Dis 42:601–604
2. Golfieri R, Barone D (2002) Nephrologic diagnosis besides ultrasonography: which other imaging methods? Guideline on the use of radiologic methods. Arch Ital Urol Androl 74:222–2237
3. Enzweiler C, Becker CR, Bruning R, Felix R, Georgi M, Knollmann FD, Lehmann KJ, Lembcke A, Reiser MF, Rogalla P, Schoepf UJ, Taupitz M, Weisser G, Wiese TH, Hamm B (2004) Value of electron beam tomography (EBT). Rofo 176:1566–1575
4. Talisetti A, Jelnin V, Ruiz C, John E, Benedetti E, Testa G, Holterman AX, Holterman MJ (2004) Electron beam CT scan is a valuable and safe imaging tool for the pediatric surgical patient. J Pediatr Surg 39:1859–1862
5. Tepe S, Memisoglu E, Kural AR (2004) Three-dimensional noninvasive contrast-enhanced electron beam tomography angiography of the kidneys: adjunctive use in medical and surgical management. Clin Imaging 28:52–58
6. Yildiz A, Tepe S, Oflaz H, Yazici H, Pusuroglu H, Besler M, Ark E, Erzengin F (2004) Carotid atherosclerosis is a predictor of coronary calcification in chronic haemodialysis patients. Nephrol Dial Transplant 19:885–891
7. Yildiz A, Memisoglu E, Oflaz H, Yazici H, Pusuroglu H, Akkaya V, Erzengin F, Tepe S (2005) Atherosclerosis and vascular calcification are independent predictors of left ventricular hypertrophy in chronic haemodialysis patients. Nephrol Dial Transplant 20:760–767
8. Vasbinder G, Nelemans PJ, Kessels AG, Kroon AA, Maki JH, Leiner T, Beek FJ, Korst MB, Flobbe K, de Haan MW, van Zwam WH, Postma CT, Hunink MG, de Leeuw PW, van Engelshoven JM, Renal Artery Diagnostic Imaging Study in Hypertension (RADISH) study group (2004) Accuracy of computed tomographic angiography and magnetic resonance angiography for diagnosing renal artery stenosis. Ann Intern Med 141:674–682
9. Boudewijn G, Vasbinder C, Nelemans PJ (2005) Accuracy of computed tomographic angiography and magnetic resonance angiography for diagnosing renal artery stenosis. Perspect Vasc Surg Endovasc Ther 17:180
10. Young N, Chi KK, Ajaka J, McKay L, O'Neill D, Wong KP (2002) Complications with outpatient angiography and interventional procedures. Cardiovasc Intervent Radiol 25:123–126
11. Leiner T, de Haan MW, Nelemans PJ, van Engelshoven JM, Vasbinder GB (2005) Contemporary imaging techniques for the diagnosis of renal artery stenosis. Eur Radiol 15:2219–2229
12. Bloch M, Basile J (2004) Clinical insights into the diagnosis and management of renovascular disease. An evidence-based review. Minerva Med 95:357–373
13. Laissy JP, Sebban V, Deux JF, Huart V, Mousseaux E (2004) Noninvasive coronary artery imaging: CT and MR. J Radiol 85:1798–1808
14. Gritsch H (2005) Update on kidney transplantation for the urologist. Curr Urol Rep 6:29–34
15. Akbar S, Jafri SZ, Amendola MA, Madrazo BL, Salem R, Bis KG (2005) Complications of renal transplantation. Radiographics 25:1335–1356
16. Baxter G (2003) Imaging in renal transplantation. Ultrasound Q 19:123–138
17. Goel M, LaPerna L, Whitelaw S, Modlin CS, Flechner SM, Goldfarb DA (2005) Current management of transplant renal artery stenosis: clinical utility of duplex Doppler ultrasonography. Urology 66:59–64
18. Lockhart M, Robbin M (2001) Hemodialysis access ultrasound. Ultrasound Q 17:157–167

19. Goldstein S, Smith CM, Currier H (2003) Noninvasive interventions to decrease hospitalization and associated costs for pediatric patients receiving hemodialysis. J Am Soc Nephrol 14:2127–2131
20. Burgos F, Pascual J, Marcen R, Garcia-Navas R, Gomez V, Ortuno J (2004) The role of imaging techniques in renal transplantation. World J Urol 22:399–404
21. Zachaus M, Herrmann V, Plehn A, Langer T, Podhaisky H (2005) Sonographic findings in the diagnostic course of vascular access for hemodialysis. Med Klin (Munich) 100:1–5
22. Weiner S (2005) Is medical radiation exposure a public health concern? The downside to technological advances in computed tomography. AHIP Cover 46:52–55
23. Miller R (1995) Special susceptibility of the child to certain radiation-induced cancers. Environ Health Perspect 103:41–44
24. Budoff M, Achenbach S, Duerinckx A (2003) Clinical utility of computed tomography and magnetic resonance techniques for noninvasive coronary angiography. J Am Coll Cardiol 42:1867–1878
25. Morin R, Gerber TC, McCollough CH (2003) Radiation dose in computed tomography of the heart. Circulation 107:917–922
26. Cote C, Notterman DA, Karl HW, Weinberg JA, McCloskey C (2000) Adverse sedation events in pediatrics:a critical incident analysis of contributing factors. Pediatrics 105:805–814