Review

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The impact of new CT technology on clinical practice

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Dr Becker's previous publications cover CT angiography of cerebral aneurysms, investigation of different CT detectors and radiation exposure and comparison of cardiac investigations between electron beam CT and conventional CT for detection and quantification of coronary calcium. Dr Becker's current focus is on CT angiography of coronary arteries and characterization of atherosclerotic plaques.

Abstract

With the introduction of multi-detector-row CT (MDCT), new applications such as cardiac CT angiography, lung and colon screening and scanning of polytrauma patients became feasible. Coronary artery disease can reliably be ruled out by MDCT and therefore the technique surpasses conventional invasive angiography in some patients. In screening for lung and colon cancer, special post-processing for dedicated analysis of the MDCT dataset is required for comfortable and safe exclusion of early tumour disease. Scanning has already replaced conventional X-ray as the first line diagnostic tool for polytrauma patients in the emergency department.

All these applications require CT image acquisition with highest temporal and spatial resolution of a certain volume within shortest period of time. These special acquisition conditions also entail special considerations about the contrast medium and form of administration. With most modern CT scanners, CT angiography is performed with high iodine delivery rates. Heat sensations, blood volume expansion and contrast-induced nephropathy are less frequent with iso-osmolar contrast media. In many instances, a highly concentrated (more than 300 mgI/ml) isosmolar contrast media appears to be the optimal contrast agent for MDCT investigations.

Introduction

Multi-detector-row CT (MDCT) scanners were first introduced into clinical practice in 1998. Four-detector-row CT with 500 ms gantry rotation and detector collimation between 5 and 1 mm allowed for both high scan speed and improved spatial resolution. A number of different clinical applications were gained from these new scanning features, such as emergency radiology, CT screening (CTS) and CT angiography (CTA). Indeed, for the first time, CTA of the coronary arteries became feasible with MDCT by a new technique called retrospective ECG gating. For this technique, the spiral CT scan is acquired with a slow table feed per gantry rotation (pitch<0.3) in conjunction with the ECG signal, which is recorded during scanning. Image reconstruction is usually performed in the slow motion diastole phase of the cardiac cycle.[1]

CT screening

CT has often been described as a sensitive tool for the early detection of morphological changes. With the increased spatial resolution offered by MDCT, it began to be more widely used to screen for lung and colon cancer as well as for coronary artery disease. All screening applications share low radiation exposure and no requirement for contrast medium administration. Dedicated post-processing software has become mandatory to support the detection of early stages of diseases by MDCT.[2]

The potential of coronary calcium screening to predict the risk of unheralded myocardial infarction has been investigated for years. Until now, CT calcium screening has failed to provide an incremental predictive value over conventional risk factors, but prospective studies are currently being performed to support this hypothesis.[3]

In lung cancer screening, multi-detector-row CT is far more sensitive than conventional X-ray imaging for the detection of intrapulmonary lesions. However, in the early days, many of these detected lesions turned out to be benign, and a number of unnecessary biopsies were performed. Meanwhile, it has been shown that lesion growth as detected by a change of lung nodule volume is a better predictor for malignancy (Figure 1). As yet, no studies are available to indicate whether detection by MDCT improves outcome in lung cancer.[4]

Virtual colonoscopy seems to be gaining wider acceptance in comparison with optical colonoscopy probably because of better patient comfort. In the future, faecal tagging may even allow this application to

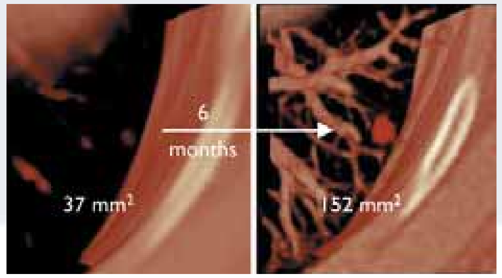

Figure 1. If a lung nodule is detected by CT lung cancer screening with a size below 5 mm, repeated scanning is performed within 6 months. The presented case demonstrates nodule growth from 37 to 152 mm² within this period of time. Surgical resection confirmed the diagnosis of stage I lung cancer.

be performed without bowel cleansing. Reliability for the detection of polyps has improved with the improved spatial resolution and faster scanning offered by the more advanced MDCT generations, explaining the difference in many of the studies published so far (Figure 2). However, data are also lacking to support the widespread use of virtual colonoscopy for screening, since colon polyps and flat lesions that may also turn into colon cancer may still be missed.[5]

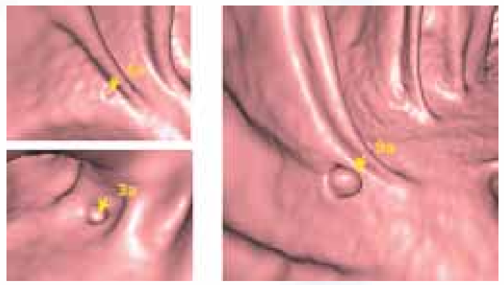

Figure 2. The newest CT scanners allow for 3D display of the inner colon wall after distension with air. In a clean bowel, it is easy to visualize any polyps that may turn into cancer over time.

CT angiography

The investigation of any vascular territory from head to toe has improved significantly with MDCT scanner generation (Figure 3). The shorter scan time and the higher spatial resolution has led to remarkable improvements in the visualization of even the smallest peripheral arterial branches. The type of contrast injection that is used for CTA basically depends on the duration of the CT scan and the delay time between contrast injection and the CT scan. With longer scan times, as for the four-detector row CT, a dual-phase contrast protocol is an advantage for compensating for contrast recirculation in the later phase of the injection and maintaining a constant and homogenous enhancement for the entire scan time. Since the MDCT scan time became shorter than 20 s with the newest CT scanner generation, only mono-phase contrast injection protocols are used. In short scans, a certain time delay appears necessary in order to allow the contrast medium to reach the targeted vascular system and to allow for the breath-hold command.

Figure 3. Peripheral run-off studies are easily performed by MDCT angiography with highest resolution. Ideally the table feed is as fast as the contrast bolus travels along the arteries.

The arrival time of the contrast medium depends on different factors and may best be determined by tracking the arrival of the contrast bolus in the target vessel, e.g. the ascending aorta. Shorter scan times also require less contrast medium for achieving a certain level of enhancement.[6]

Iodinated contrast media are available with different concentrations ranging between 140 and 400 mgI/ml. Contrast media with higher concentrations may allow the achievement of higher vessel enhancement than lower concentration contrast media with the same flow rate. However, increasing the flow rate with low concentration contrast media will also allow a similar

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enhancement to be achieved as with high-density contrast media. For this reason, it seems reasonable to deal with the iodine delivery rate (grams of iodine per second) in order to calculate the ideal flow rate for a certain contrast concentration. The iodine delivery rate simply corresponds to the product of the contrast media flow and concentration and should ideally be in the range of 1.5–2 g of iodine per second for a CTA study.

Highly concentrated contrast media may be preferable in order to achieve iodine delivery rates with low flow rates. However, highly concentrated contrast media tend to have a higher viscosity compared to less dense contrast media. As a result of the high viscosity, the contrast medium does not mix well with the blood and the final enhancement may therefore vary more often from patient to patient and may more often be related to physiological factors such as the blood volume and circulation time. Warming to body temperature (37 °C) prior to administration will significantly reduce the viscosity of the contrast media.[7]

Non-ionic low-osmolarity monomeric contrast media are most commonly used for CT and angiography. As an alternative, non-ionic iso-osmolar dimeric contrast media are available for intravenous administration. In general, iso-osmolar contrast media may be preferable in any vascular territory where the endothelium is sensitive to the osmolarity such as the brain, heart and kidneys. In the brain, for instance, it has been shown that iso-osmolar contrast media affect the blood–brain-barrier to a lesser degree than low-osmolar contrast media.[8] The rhythm and the function of the heart may also be influenced to a lesser degree by isosmolar as compared to low-osmolar contrast media. Temporary impairment of renal function may occur after the use of contrast media. Contrast-induced nephropathy (CIN) has been observed less commonly with a isosmolar contrast medium than with a low-osmolar contrast medium in patients at risk undergoing cardiac catheterization.[9] Hydration prior to the administration of contrast media and a reduction in the amount of iodine appears mandatory for preventing CIN.

In relation to the osmolarity of the contrast media in use, water may be pulled out of the interstitium into the vascular system, resulting in blood volume expansion. Patients with impaired cardiac function may be at risk of decompensation caused by right heart volume overload. Therefore, iso-osmolar contrast media may be preferable in these patients.[10] In addition, patients less commonly complain about pain or heat sensations related to the administration of iso-osmolar contrast media. On the other hand, some studies have reported that late allergic skin reactions may be more commonly associated with the administration of isosmolar contrast media.

Cardiac CT

The vessel enhancement should be as high as possible for the assessment of the coronary artery lumen and its patency. The brightest enhancement may also help in visualizing the smallest branches in the periphery of the coronary artery tree (Figure 4). A very recent publication comparing coronary 64-slice CT angiography with conventional cardiac catheterization described remarkably high sensitivities, specificities and positive and negative predictive values in the range of 87–99%.[11] Coronary CT angiography is also well suited to visualizing the anatomy in patients with coronary anomalies and identifying patients in whom the aberrant coronary artery runs between the ascending aorta and the pulmonary outflow tract. In this particular location, the coronary artery is at risk of being squeezed in between the two major vessels, which may subsequently result in myocardial ischaemia. Coronary

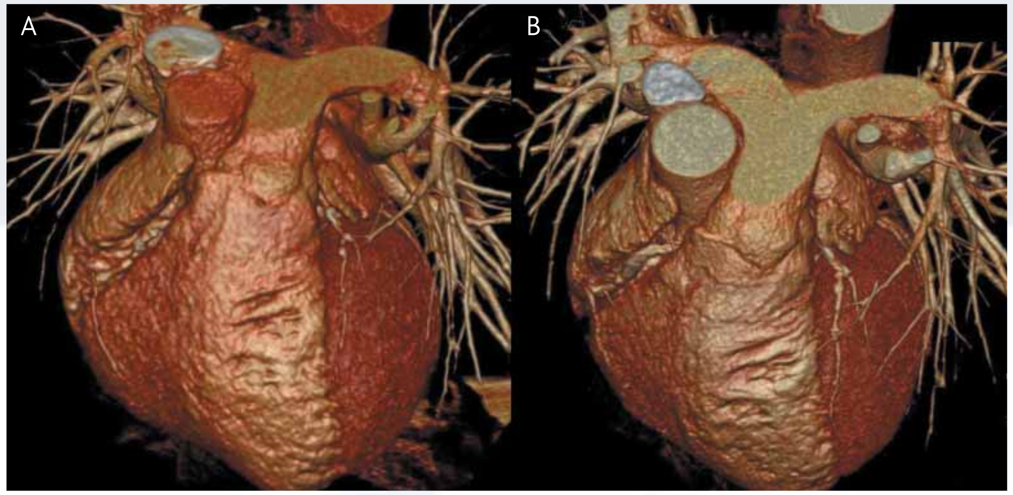

Figure 4. Higher iodine delivery rates (A = 1 g iodine per sec; B = 1.5 g iodine per sec) results in better visualization of the smallest vessels and branches of the coronary arteries, as well as of the pulmonary arteries.

CT angiography may also provide valid and useful information in patients with vasculitis and aneurysms, fistulas or dissection.

If the potential of coronary CT angiography for the direct detection of vulnerable plaques in patients with acute coronary syndromes is realised, new strategies will need to be considered for the appropriate treatment of these patients. Non-invasive vulnerable plaque detection may probably justify intensive medical treatment or may lead to invasive approaches such as plaque sealing.

CT angiography may soon serve as a tool for a complete diagnostic work-up of patients presenting with atypical chest pain. A single CT angiography investigation will allow pulmonary emboli, aortic dissection or coronary thrombus to be either ruled in or out (Figure 5).

CT emergency

MDCT scanning provides a rapid overview even in critically ill patients that need observation at the same time. It is therefore quite logical that MDCT scanners have been installed in some institutions dedicated to emergency treatment, replacing conventional imaging almost completely where available. Any spine, bone or joint trauma as well as any vessel injury and

Figure 5. For scanning the chest with bright contrast in the pulmonary arteries, aorta and coronary arteries simultaneously, the contrast bolus needs to be stretched and low iodine delivery rates (1 g iodine per sec) must be used.

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parenchymal laceration can be displayed within a few seconds. MDCT simultaneously provides important information about the localization, severity and extent of bleeding or ischaemia.

Future technical and clinical potentials

The use of MDCT for emergency investigation has become a routine application. Non-invasive CTA imaging of the coronary arteries is the main driver of further developments in MDCT. Some technical improvements in MDCT are foreseeable within the next few years, such as shorter exposure times and higher spatial resolution. Exposure times will become short enough to scan the coronary arteries at any heart rate without the necessity of administering b-blockers and the higher spatial resolution will reduce artifacts caused by metal or calcium. Once these requirements are fulfilled, coronary CT angiography performed with very little contrast media may replace cardiac catheterization for the triage of patients for conservative, interventional or surgical therapy. Thus, it may reduce the use of invasive diagnostic procedures in pre-selected patients in whom coronary interventions are essentially required.

The widespread adoption of MDCT for screening will mainly depend on the results of studies currently underway investigating the reliability and efficiency of this new application.

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