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Technical principles of dual source CT

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ABSTRACT

During the past years, multi-detector row CT (MDCT) has evolved into clinical practice with a rapid increase of the number of detector slices. Today's 64 slice CT systems allow whole-body examinations with sub-millimeter resolution in short scan times. As an alternative to adding even more detector slices, we describe the system concept and design of a CT scanner with two X-ray tubes and two detectors (mounted on a CT gantry with a mechanical offset of 90°) that has the potential to overcome limitations of conventional MDCT systems, such as temporal resolution for cardiac imaging. A dual source CT (DSCT) scanner provides temporal resolution equivalent to a quarter of the gantry rotation time, independent of the patient's heart rate (83 ms at 0.33 s rotation time). In addition to the benefits for cardiac scanning, it allows to go beyond conventional CT imaging by obtaining dual energy information if the two tubes are operated at different voltages. Furthermore, we discuss how both acquisition systems can be used to add the power reserve of two X-ray tubes for long scan ranges and obese patients. Finally, future advances of DSCT are highlighted.

1. Introduction

The advent of 64-slice CT systems has further substantiated CT imaging of the heart in clinical routine [1]. The achieved examination times of 5–10 s lead to short breath hold times, even for patients with dyspnea. Spatial resolution is sufficient for the evaluation of small anatomical details like coronary arteries and plaques. In particular, with double z-sampling applied to 0.6 mm slices, isotropic spatial resolution of 0.4 mm can be obtained, along with a reduction of spiral artifacts [2]. With the trend towards increasing detector z-coverage, less cardiac cycles contribute to the acquisition data. This shortens the total examination time and reduces the number of potential stair-step artifacts, but increases the risk of distortion of larger fractions of the entire data if ectopic heart beats occur. A new stage of clinical performance can probably be expected from CT systems with the ability to scan the whole heart in one cardiac cycle. Still, motion artifacts due to limited temporal resolution are one of the most important challenges in cardiac imaging, even with today's available detector z-coverages. A temporal resolution of better than 100 ms independent of the heart rate is desirable for robust cardiac imaging in clinical routine. In this context, increased gantry rotation speeds appear more appropriate than multi-segment reconstruction approaches [3]. However, rotation times of less than 0.2 s which are required to provide a temporal resolution of 100 ms or better are associated with vast centrifugal forces (>75 G), and are beyond today's mechanical limits. Although non-mechanical approaches like electron-beam CT can accomplish a temporal resolution even below 100 ms, they are not considered adequate for state-of-the art cardiac imaging due to inherent disadvantages such as compromised signal-to-noise ratio and limited spatial resolution [4]. An alternative concept to improve temporal resolution in combination with the excellent imaging capabilities of today's 3rd generation CT systems is a scanner with multiple sources and detectors [5–8]. In this article, we describe the system concept and design of a dual source CT (DSCT). We derive its characteristic features and benefits for cardiac scanning, non-cardiac scanning, and dual energy scanning. Finally, we present an outlook towards future developments in dual source CT and their consequences for clinical applications.

2. Dual source CT system concept and design

The idea of an advanced 3rd generation system concept with two sets of tube-detector pairs has already been proposed only a few years after CT became clinical practice [5,6]. Its first technical realization [8], with the two acquisition systems mounted at an angular offset of 90° on the rotating gantry, is schematically shown in Fig. 1. One detector (detector A) covers a typical measurement

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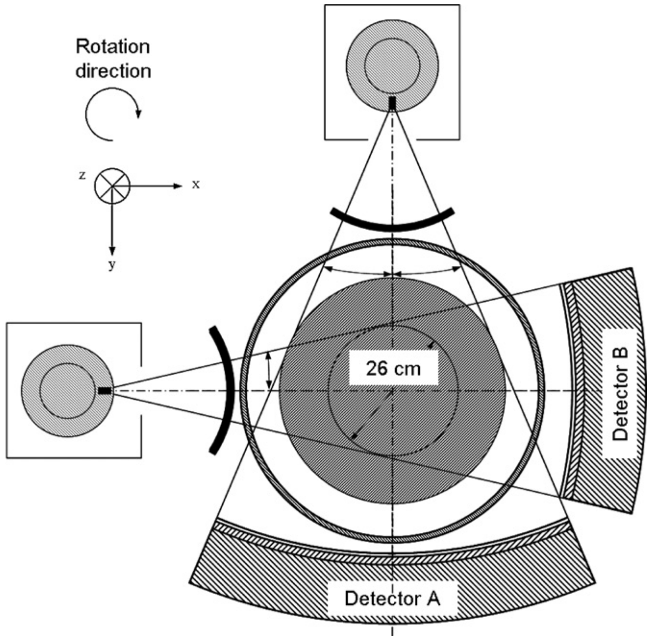

Fig. 1. Schematic illustration of the dual source acquisition geometry using two tubes and two corresponding detectors, mounted into the gantry with an angular offset of 90° (modified from [8]).

field of 50 cm. To preserve compact system geometry, the second detector (detector B) covers a smaller measurement field of 26 cm. Each detector consists of an adaptive array of 40 rows, which allows choosing between an acquisition configuration of 32 × 0.6 mm and 24 × 0.6 mm slices. With a *z*-flying focal spot technique [2,9], a sampling distance of 0.3 mm can be achieved at the isocenter: every detector acquires 64 overlapping slices per rotation from two subsequent 32-slice readings with 0.6 mm collimation. Gantry rotation times are 0.33 s, 0.5 s, and 1.0 s. A peak power of 80 kW is provided by each of the two X-ray tubes (STRATON, Siemens Health Care, Forchheim, Germany [10]). Both tubes can be operated independently with respect to voltage and current settings.

Special attention has to be paid to scattered-radiation: with an object in the scan field, the presence of a second tube induces scatter in the first detector and vice versa. These supplementary photons cannot be completely suppressed by anti-scatter grids. Therefore, dedicated scattered-radiation correction algorithms are employed in order to prevent image degradation and to restore image contrast. Yet another challenge is data truncation. Since detector B is restricted to a small, central field of view (26 cm in diameter), its projection data are potentially truncated for larger scan objects, and the data will have to be extrapolated (see below).

3. Characteristic features of dual source CT

The main characteristic feature of dual source CT is the flexibility it offers with respect to modes of operation and the possibility to combine the resulting acquisition data. After detector B data with the smaller scan field are extrapolated to a full-size detector using detector A data at the same projection angle [7], dual source acquisition data can be used in a multitude of ways.

3.1. Cardiac scanning

The first key benefit of DSCT is improved temporal resolution. In general, partial scans are used for cardiac image reconstruction. At least 180° of parallel-ray projections are needed to reconstruct an image. A single source CT scanner needs half a rotation plus the fan angle (about 50° to 60°) to deliver this amount of data, and the temporal resolution in the center of rotation is half the rotation time. At the same rotation speed, the temporal resolution of a single source scanner can be improved by splitting the half-scan data-sets into smaller segments, which are obtained from consecutive cardiac cycles. This multi-segment approach [11,12] relies on the assumption that there is negligible variation in the position of the coronary arteries between each cardiac cycle. In addition, the cardiac motion cycle needs to be properly de-synchronized with respect to the gantry rotation: complementary data segments, acquired during different cardiac cycles but at the same cardiac phase, add up to a half-scan sinogram. However, the temporal resolution with this approach strongly depends on the patient's heart rate and a stable and predictable heart motion.

With a dual source scanner, on the other hand, two partial data segments, shifted by 90° rotation angle are simultaneously acquired at the same anatomical level. The two sets of projection data are combined to a complete (180°) sinogram (see Fig. 2). Since each measurement system needs to contribute only 90° of data, the exposure time is decreased by a factor of two and only data from one cardiac cycle are used to reconstruct an image. Hence, with DSCT, a constant temporal resolution of a quarter of the gantry rotation time is achieved, independent of the patient's heart rate. For a gantry rotation time of 0.33 s, a robust temporal resolution of 83 ms is established (see Fig. 3). To further increase temporal resolution, multi-segment approaches can be applied to DSCT as well: the 90° data segments of each of the two detectors can be independently subdivided into smaller segments, which are acquired in successive

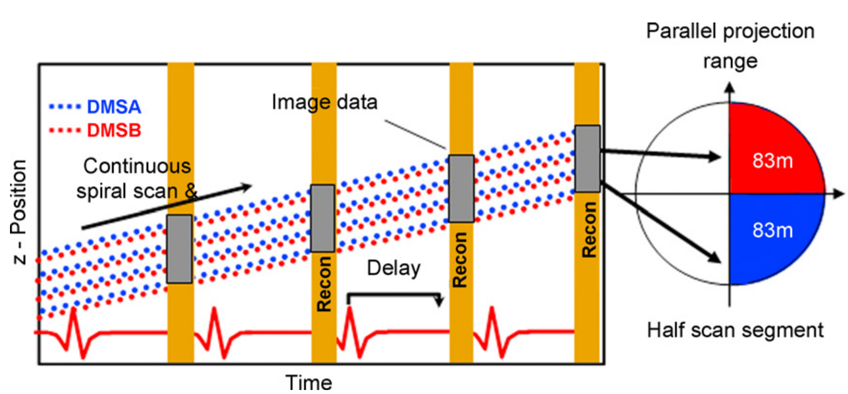

Fig. 2. Principle of ECG-controlled multi-slice spiral image reconstruction for a dual source CT system. By virtue of the 90° offset between the two measurement systems, 180° of parallel-ray geometry data can be split into two data segments of 90°. Both 90° data segments are acquired simultaneously at the same anatomical level within a quarter of the gantry rotation time. The principle of simultaneous acquisition of 90° data segments can be applied to cardiac step-and-shoot acquisition with a dual source CT scanner as well.