Current Exposure Practice with Multislice CT

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Introduction

Since the introduction of the first multislice CT (MSCT) scanner in 1992 (Elscint CT Twin), there has always been guesswork on its implications for the radiation exposure of the patient: doubled (two slices instead of one), or cut to half (reduced total mAs)? Indeed, nothing should have changed at a first glance: by simultaneously scanning several slices, the dose-length product per scan (or rotation) increases by as much as the number of scans (or rotations) decreases for the same body region. On closer inspection, however, things are not the same anymore. There are a number of new influencing parameters specific to MSCT which systematically increase or reduce patient dose compared to single-slice scanners. In addition, the improved utilisation of tube output allows for significant changes in scan protocol settings. The ability to scan a given volume in the same time with reduced slice thickness, thus enabling the production of 'isotropic voxels', is the most prominent implication.

Therefore the question arises whether the introduction of MSCT is associated with a reduction or an increase in patient exposure in practice. With some delay, the first papers were published in 2001 in which the dose values resulting from MSCT were compared with those from single-slice scanners (SSCT) previously used at the same institution. All of them reported on a significant increase in patient dose following the introduction of MSCT technology.

These findings were the reason to conduct a nation-wide survey on MSCT practice in Germany at the beginning of 2002 similar to that in 1999 for single-slice CT. With more than 200 MSCT scanners installed and a participation rate of more than 50%, representative data reflecting the exposure practice on dual- and quad-slice scanners were obtained.

Current MSCT Dose Level

The most interesting question was how MSCT exposure compares with singleslice CT (SSCT) practice. To answer this question, the average values of the 1999 SSCT survey were used for benchmarking purposes. In order to characterise the dose level by a single value only, the unweighted mean of all 14 standard CT examinations is used. The dose descriptors are the effective CT dose index $CTDI_{w,eff}$ (i.e. weighted CTDI divided by pitch, newly also named 'volume CTDI ($CTDI_{vol}$)'), and the dose-length product per examination, DLP_w. While

$CTDI_{w,eff}$ depends only on the scan protocol settings (tube voltage, tube current, exposure time, slice collimation, pitch), DLP_w per examination in addition takes user-specific preferences (scan length and number of scan series) into account.

The results of this comparison are shown in fig. 1. With $CTDI_{w,eff}$ as the descriptor of local dose, the relative dose level of all MSCT scanners is slightly below the mean value of all scanners participating in the '99 survey. While duals are found at about 65%, quads are operated at the same level as the average SSCT scanner. With DLP_w as the descriptor of integral radiation exposure, the results are similar, but slightly higher owing to the somewhat increased average scan length of examinations carried out with MSCT scanners.

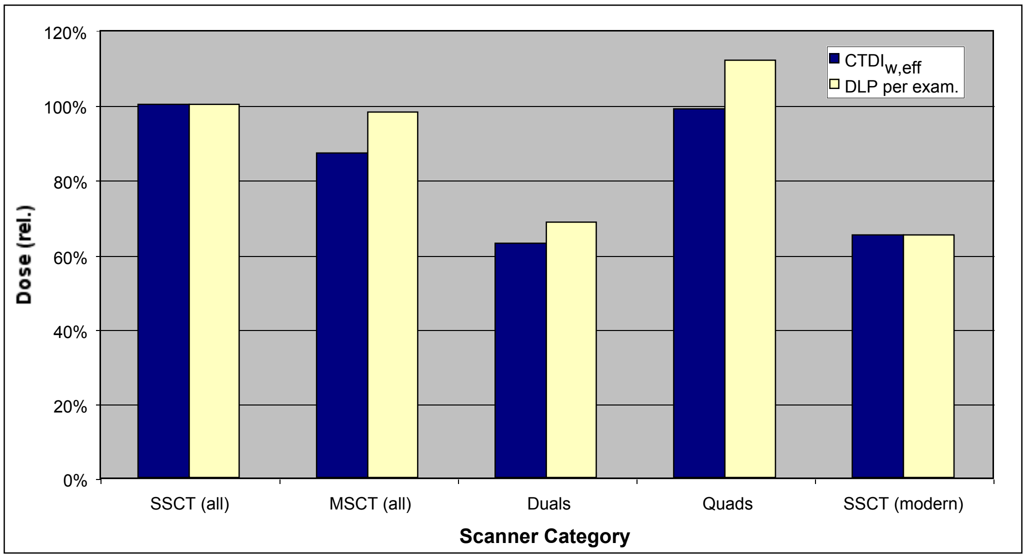

Figure 1: Comparison of the average dose levels of MSCT and SSCT scanners for local dose ($CTDI_{w,eff}$) and integral radiation exposure (DLP_w). A relative dose level of 100% refers to the overall average of the 1999 survey on SSCT practice (for details see text).

These results indicate that – contrary to the impression given by the publications mentioned above – there is no dramatic increase in patient exposure following the introduction of MSCT technology when compared to the average SSCT exposure practice in Germany. However, as MSCT scanners represent state-of-the-art technology, a comparison with modern SSCT scanners (i.e. spiral scanners with solid-state detectors) used as a reference is more appropriate. The factory settings of most of these single-slice scanners, when benchmarked in the same way, result in overall dose levels of about 65%. The same dose levels have been found on average for the users of dual-slice scanners in this survey. Compared to this more relevant reference, the overall dose level of quad-slice scanners based on DLP_w is currently higher by a factor of almost two.

Reasons for Non-optimised MSCT Practice

Primarily, three causes have been identified as being responsible for the increased dose levels presently associated with the use of quad-slice scanners:

- **Reduced slice collimation and slice thickness:** In fig. 2, both the slice collimation used for data acquisition and the reconstructed slice thickness are compared with those employed in SSCT scanning. While the average slice thickness amounts to 6.4 mm for SSCT, the average slice collimation employed on quad-slice scanners is 2.4 mm only. However, image noise is determined by the reconstructed slice thickness as this is used for image presentation. Therefore the majority of users retrospectively combines thin slices into a thicker one, either by reconstruction or by post-processing, thus reducing image noise. Nevertheless, the average reconstructed slice thickness, which amounts to 4.4 mm, remains significantly smaller compared with SSCT practice. Obviously, many users felt the need to compensate for the increased noise associated with thinner slices by increased dose settings.

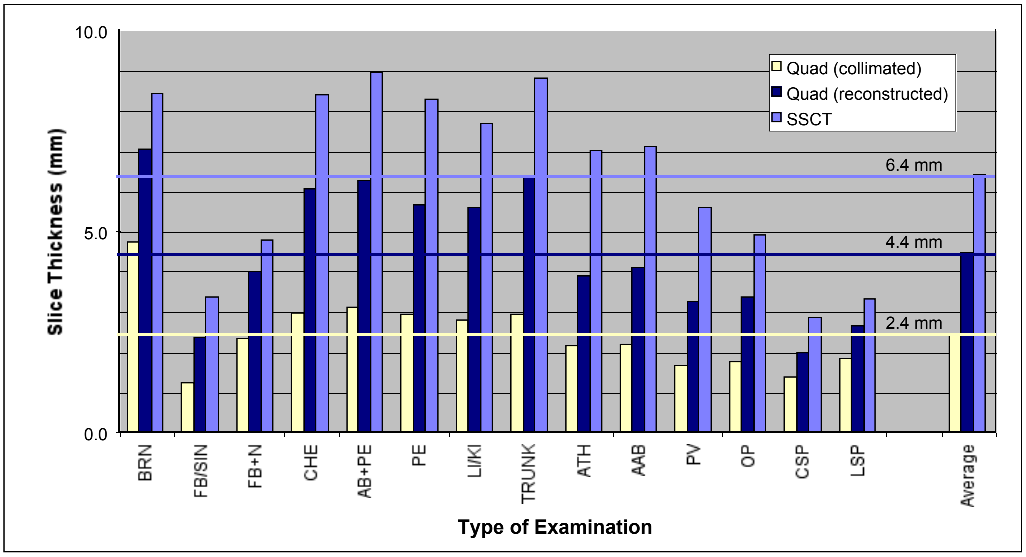

Figure 2: Collimated and reconstructed slice thickness for SSCT and quad slice MSCT scanners. Both collimated and reconstructed slice thickness used with quad scanners (2.4 and 4.4 mm, respectively) is much lower compared to SSCT practice (6.4 mm, collimated = reconstructed) on average (types of examination: BRN = routine brain, FB/SIN = facial bone/sinuses, FB+N = facial bone + neck, CHE = routine chest, AB+PE = routine abdomen (total), PE = routine pelvis, LI/KI = liver/ kidneys, TRUNK = whole trunk, ATH = CTA thoracic aorta, AAB = CTA abdominal aorta, PV = CTA pulmonary vessels, OP = osseous pelvis, CSP = cervical spine, LSP = lumbar spine) .

- **Overbeaming:** ‘Overbeaming’ is caused by wider collimator settings in order to avoid penumbral effects in the outer portions of the detector array. With wide collimation (4 * 5 mm; fig. 3a), the resulting increase in dose of between 10% and 25%, depending on the type of scanner, may still appear acceptable. With narrow collimation (4 * 1 mm; fig. 3b), however, the dose increase amounts to between 40% and 100%, and significantly exceeds the 100% level for sub-millimetre slices. Due to the preference for scanning with narrow slice collimation, overbeaming constitutes a major dose handicap for users of quad-slice scanners in daily practice. It should be noted, however, that the overbeaming of the majority of quad scanners installed in Germany is comparatively small. Therefore the impact of overbeaming on the overall dose level may be even higher in other countries where the spectrum of scanner models differs from Germany.

- **mAs per slice (or effective mAs) conception:** This aims to keep both slice profile width and image noise constant when changing the pitch factor. As the effective mAs product must also be kept constant, the electrical mAs product must necessarily be modified accordingly. This is done automatically on the majority of MSCT scanners installed in Germany. Varying the pitch therefore no longer influences patient dose; pitch merely serves as a parameter to control the acquisition speed. This conception is sound, but rarely understood. Consequence: dose is intuitively underestimated if pitch is selected larger than 1. Reversely, dose is not increased for pitch settings less than 1, at least as long the effective mAs product remains unchanged.

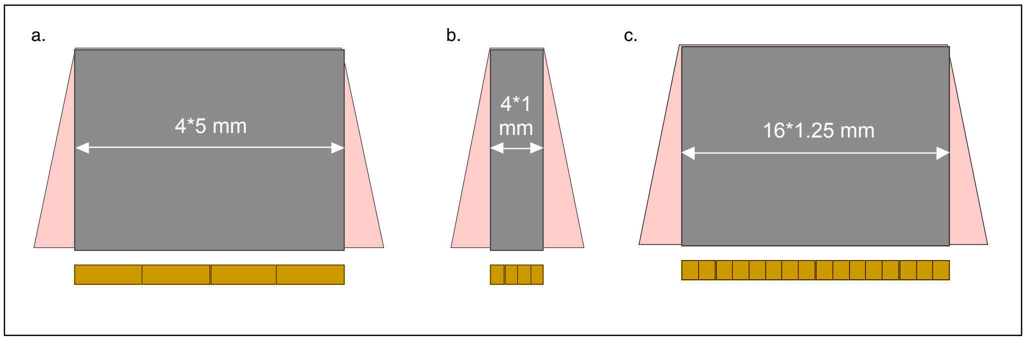

*Figure 3: Dose increase due to overbeaming for different collimator settings and types of MSCT scanners. For quad-slice scanners with wide collimation (4 * 5 mm; fig. 3a), the increase in dose due to overbeaming is moderate. With narrow collimation (4 * 1 mm; fig. 3b), however, a considerable dose increase is noted that significantly exceeds the 100% level for sub-millimetre slices. For a 16-slice scanner with narrow collimation (16 * 1.25 mm; fig. 3c), overbeaming is reduced so that the dose increase is the same as for a quad-slice scanner with wide collimation (fig. 3c).*

Suggestions on How to Optimise MSCT Practice

The increased noise and the extended overbeaming associated with the preferred use of narrow slice collimation is the most important implication of MSCT scanning. The key factor towards optimisation of current MSCT practice is how to handle this issue.

- **How to avoid excessive overbeaming:** As overbeaming is most pronounced on quad-slice scanners (and some dual-slice scanners also), data acquisition with very narrow slice collimation should be avoided unless there is a real need to do so (e.g. for multi-planar reformatting (MPR) or if improved spatial z-resolution is mandatory). Otherwise, scanning should be made with medium or wide collimation. This particularly holds for those scanners, which exhibit a comparatively high overbeaming. For 16-slice scanners, overbeaming is much less and therefore requires no special attention.

- **How to face increased noise:** In order to reduce image noise, it is recommended to reconstruct thicker slices (multi-planar volume reconstruction, MPVR). This is already practised by the majority of MSCT users, although the average (reconstructed) slice thickness still remains significantly smaller than for SSCT scanners. Another fact, however, deserves much more attention: the reduction of partial volume effects. The Hounsfield values (contrasts) of small details improve linearly with reduced slice thickness, whereas quantum noise only increases with the square root of the slice thickness ratio. Therefore, if a narrow slice thickness is used, the visibility of small details improves despite increased noise. This is clearly demonstrated by the example given in fig. 4, where the visibility of a liver lesion (approximately 3 mm in size) diminishes continually with increasing slice thickness - despite reduced image noise. Consequently, there should be no absolute need to increase dose when making use of thinner slices.

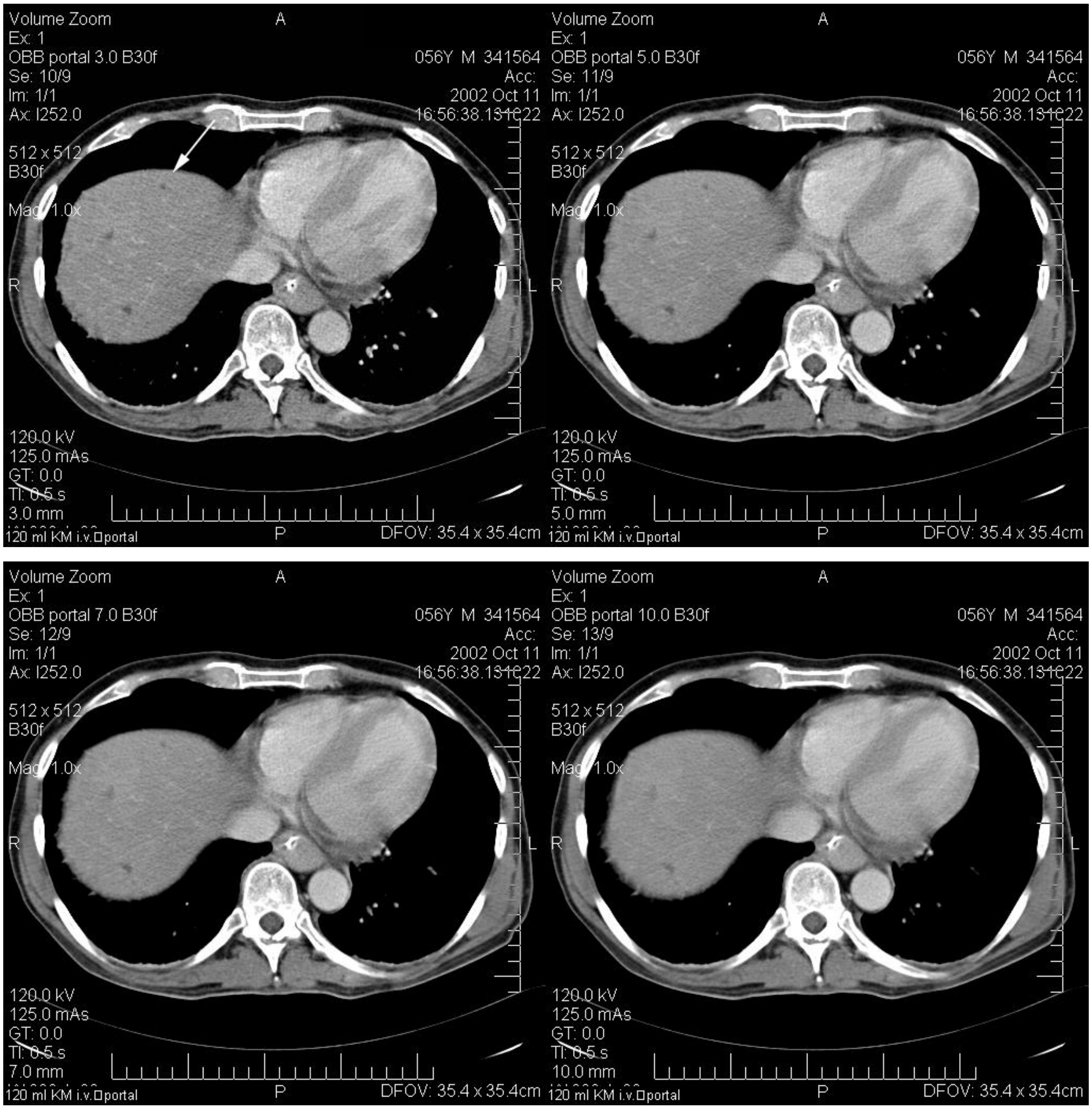

*Figure 4: MSCT examination of the liver performed on a Siemens Somatom Volume Zoom at 120 kV, 4*2.5 mm slice collimation and 125 mAs_{eff} ($CTDI_{w,eff}$ = 11 mGy). From the same raw data set, slices of different thickness [3 mm (upper left), 5 mm (upper right), 7 mm (lower left), and 10 mm (lower right)] were reconstructed at the same central position z_0. Despite the increased noise pertaining for thinner slices, the visibility of small lesions improves remarkably owing to reduced partial volume effects. This is clearly demonstrated by a lesion approximately 3 mm in size (arrow) (courtesy Dr. Wedegaertner, University Hospital Eppendorf, Hamburg, Germany).*

- **Technical means:** Dose reduction will further be facilitated by a variety of technical measures. Meanwhile, all CT manufacturers have developed systems for automatic dose control. These adjust the mAs product to individual patient size and shape and are currently employed in the latest generation of MSCT scanners (for details see NAGEL et al 2002). Dedicated smoothing filters, which preserve spatial resolution, are another approach. Even more sophisticated solutions can be expected on medium term.
- **Education:** The 1999 SSCT survey already revealed the need to improve the skills of CT users with respect to all CT related dose topics (dose descriptors, impact of parameter settings on dose and image quality, dose assessment, optimisation). MSCT with its increased complexity has further aggravated this issue. About 70% of the returned questionnaires contained severe discrepancies, which necessitated at least one additional query. This indicates that most MSCT users are not yet familiar with the peculiarities introduced by this new technology. Dedicated training courses for CT users, as required in the European directive for radiation protection of the patient, should be established and should become mandatory.
- **Standardisation of user interfaces:** At present, there is no conformity between the CT manufacturers on the parameters used for setting up scan protocols for MSCT. Consequently, simple questions for the settings of tube current, exposure time (or mAs product), slice collimation, table feed, slice thickness, and pitch have become nontrivial in MSCT. A standardisation of the user interfaces, at least with respect to the scan parameters applied, is overdue and should help to better understand the peculiarities of MSCT.

Summary

The current MSCT dose level has found to be less dramatic than could have been expected from early findings in publications related to this topic. However, when compared to modern single- and dual-slice CT scanners, there is a need for optimisation. The key factor to achieve this goal is to accept that noise plays a different role if thin slices are routinely acquired. Reduced partial volume effect more than compensates for increased noise, thus providing an even improved contrast-to noise ratio. Technical means, such as automatic dose control, will help to further reduce dose. Dedicated training courses for MSCT users and the standardisation of scan parameters presented at the user interfaces are deemed necessary to ensure a dose-conscious use of MSCT technology and its clinical benefits.

Suggested Reading

1. Nagel HD (ed), Galanski M, Hidajat N, Maier W, Schmidt T (2002) Radiation exposure in computed tomography – fundamentals, influencing parameters, dose assessment, optimisation, scanner data, terminology. CTB Publications, Hamburg (contact: ctb-publications@gmx.de)
2. Brix G, Nagel HD, Stamm G et al. (2003) Radiation exposure in multi-slice CT versus single-slice spiral CT: results of a nationwide survey. Eur. Radiol. 13: 1979-91
3. Nagel HD (2004) Radiation dose issues with MSCT. In: Reiser MF, Taskahashi M, Modic M, Becker CR (eds) Multislice CT 2nd revised edition. Springer, Berlin Heidelberg New York, pp 17-26