Radiation Dose Issues with MSCT

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1. Introduction

In 1992, the first third generation scanner with more than a single row of detectors (Elscint CT Twin) was introduced on the market. The simple fact that it was now possible to scan two slices simultaneously gave rise to some guesswork as to how this might affect patient dose. Whereas some believed that the patient dose must double (because two slices were irradiated instead of one), others argued that the dose was rather halved instead (because the total mAs product was reduced by a factor two).

When multi-slice scanners (MSCT) with many more rows were introduced in 1998, the situation became even more obscure owing to a misleading use of the term "pitch" by the majority of manufacturers. Now, large pitch values such as 3, 4, 6, etc., became customary, thus implying that patient dose might have been reduced accordingly. Indeed, however, these pitch values merely characterised the improved volume coverage of the scanners. In addition, some manufacturers made use of a modified, pitch-corrected definition of mAs ('mAs per slice' or 'effective mAs'), whereas the others retained the customary electrical mAs definition.

With respect to the radiation exposure of the patient, nothing should have changed by the introduction of MSCT 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 a given volume. Thus, the reduction in total mAs product, which simply reflects the improved utilisation of tube output, can no longer be used as an indicator of patient exposure.

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.

After setting-up the first quad-slice scanners, the primary concern was to define new examination strategies and protocol settings, thereby attributing a lower priority to dose aspects. With some delay, the first papers were published in which the dose values resulting from MSCT were compared with those from single-slice scanners (SSCT) previously used at the same institution (e.g. COHNEN et al. 2001, GIACOMMUZZI et al. 2001, HUDA and MERGO 2001). All of them observed a significant increase in patient dose following the introduction of MSCT technology.

These findings, however, suffer from the fact of being based on local scan practice only. Therefore, a broad-scale survey on MSCT practice was overdue. In this chapter, the most important results of the first dedicated MSCT survey world-wide shall be presented and compared with those from a previous survey for SSCT scanners. First, however, the parameters specific to MSCT, which systematically influence patient dose, shall be specified and discussed. Finally, suggestions are made as to how to optimise MSCT practice with respect to patient dose and image quality.

2. MSCT-Specific Influencing Parameters

2.1 MSCT-Specific Dose Advantages

There are at least two scenarios where patient dose is likely to decrease with MSCT:

- By scanning thin slices, one single data set is acquired which can simultaneously be used for images with either high resolution or standard resolution ('combi scan'), depending on the reconstruction filter and the number of slices which are retrospectively combined. In chest examinations, one scan series instead of two (standard plus HR) is sufficient. The same holds true

for, e.g. generating axial, coronal and oblique images of the facial bone and sinuses by secondary reformation from the same set of axial scan data (‘virtual gantry tilt’).
- With increased scanning speed, facilitated by both a shorter rotation time and a wider beam, the ability to cover the entire scan volume within a single breath-hold is much improved. Thus, the incidence of motion artefacts and the need for repeated examinations is reduced.

2.2 MSCT-Specific Dose Penalties

However, there are other factors involved in multi-slice scanning whereby patient dose is likely to increase. These are either inherent to the principle of multi-slice scanning or a consequence of insufficient experience of the peculiarities of this modified scanning technique:

- The single detectors in a multi-row, solid state detector array are separated by narrow strips (‘septa’) which are not sensitive to radiation and therefore do not contribute to detector signal. Due to the large number of strips, these inactive zones result in minor or major geometrical losses, depending on the design of the detector array. In addition, further losses occur due to a decrease in sensitivity at the edges of each row that results from cutting the scintillator crystal. In contrast to a single-row detector array whose width can be larger than the maximum slice thickness (see fig. 1), the edges of the rows in a multi-row detector array are located inside the beam. Due to both these effects - separating strips and decreased sensitivity - the net efficiency of a solid state detector array is decreased.
- For multi-slice scanners with more than two detector rows, the primary collimation must necessarily be made wider than N times the selected slice thickness in order to avoid (or at least to reduce) penumbral effects in the outer portions of the detector array (‘overbeaming’, see fig. 2). This becomes more serious for smaller slice collimations (McCOLLOUGH and ZINK 1999). (Overbeaming is a characteristic of multi-slice CT which is most pronounced with quad-slice scanners (N=4) and becomes smaller when N is extended to more than four slices.)
- By using cone beams instead of fan beams, the incidence of scatter is increased which requires the use of either more dose to preserve the contrast-to-noise ratio (CNR) or technical means associated with a decrease in geometric efficiency.
- ‘Overranging’, i.e. the elongation of the scan range to provide the data points required for interpolation at the beginning and at the end of a scan, is larger with MSCT in principle. At present, with a maximum total width of the detector arrays of between 20 and 32 mm, overranging is still not a major issue. This will change in future, however, as soon as much wider arrays will become available.
- It seems attractive to work with pitch settings where some overlap occurs; this will result in increased dose as long as mAs is not adapted accordingly.
- Radiation delivered from the X-ray tube is used more efficiently; therefore larger volumes can be scanned (e.g. the entire trunk). Alternatively, the tube loading can be increased if the volume remains the same.
- The same volume can be scanned with thinner slices without increasing scan time. More dose seems to be

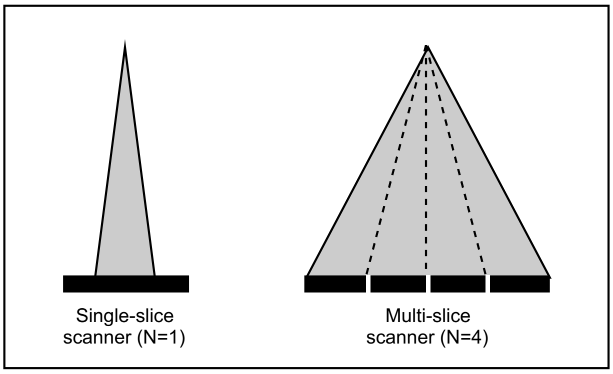

Fig. 1
MSCT scanner, with simultaneous scanning of four slices, compared with a conventional single-slice scanner. In contrast to a single-row detector array whose width can be larger than the maximum slice thickness, the edges of the rows in a multi-row detector array are located inside the beam, giving rise to reduced geometrical efficiency.

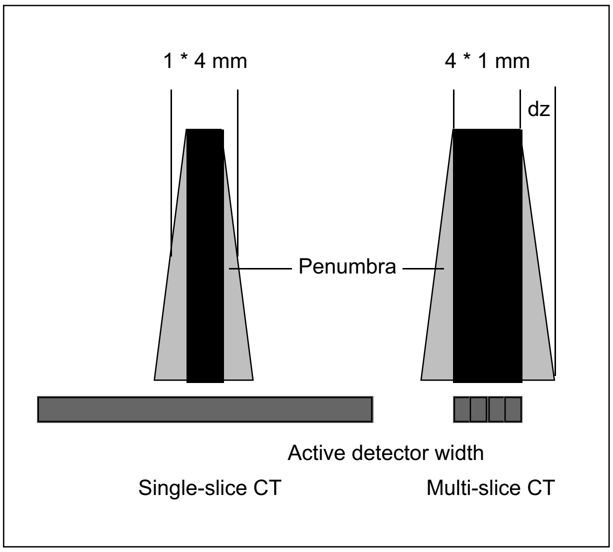

Fig. 2
*‘Overbeaming’ caused by wider collimator settings in order to avoid penumbral effects in the outer portions of the detector array. Dose is increased by up to 100% if small slices (e.g. 4 * 1 mm) are acquired. The overbeaming parameter, dz, is equal to the width (in z direction) of the rectangle which is obtained by combining the penumbra triangles at both edges of the dose profile at the detector array.*

necessary, at least in clinical indications limited by noise, when thinner slices are used in order to improve spatial resolution in the z-direction.

- There are new applications such as CTA of the coronary arteries which are preferentially performed with retrospective ECG gating, thereby making use of selected intervals during the cardiac cycle only while exposing the patient during the entire cycle.

2.3 Overbeaming

Of all the influencing factors mentioned above, 'overbeaming' is presently the most serious handicap for quad-slice scanners. 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. Beyond quad-slice scanners (e.g., with 8- and 16-slice scanners), overbeaming becomes smaller since the ratio between the overbeaming parameter, dz, and the total collimation, N * h, decreases as the number of slices, N, increases (fig. 3c).

On some, but not all single-slice scanners with the slice collimation set to values below 2 mm, the patient is also over-exposed by up to a factor 2 due to post-patient collimation. In SSCT, the use of narrow slices is restricted to selected types of examinations and short scan ranges due to limited tube loading capacity. In MSCT, however, which is much less subject to technical limitations, narrow slice collimation is the preferred scanning mode. Therefore, overbeaming, which was practically negligible with SSCT scanners, is a particular issue for MSCT scanners.

Consequently, dose assessment for multi-slice scanners must necessarily take the overbeaming effect into account. This can be achieved by applying an overbeaming correction which ensures that CTDI values, which refer to a specific total collimation, $N \cdot h_{ref}$, are adjusted in order to apply also to other collimator settings. In this context, the decisive quantity is the overbeaming parameter, dz. This is equal to the width (in z direction) of the rectangle, which is obtained by combining the penumbra triangles at both edges of the dose profile at the detector array (see fig. 2). For all existing MSCT scanners, this parameter has turned out to be a constant value (independent of collimator setting), which is determined by the focal spot size and the distances between focal spot, primary collimator and axis of rotation for the particular scanner model.

The overbeaming correction factor, k_{OB}, is then calculated according to

$$k_{OB} = \frac{N \cdot h_{ref} \cdot (N \cdot h + dz)}{N \cdot h \cdot (N \cdot h_{ref} + dz)} \quad (1)$$

The appropriate values for N, h_{ref} and dz for the scanner under consideration can be taken from the dose-relevant scanner data which have been compiled in the appendix of NAGEL et al. 2002.

2.4 Lack of Transparency

Moreover, the transparency of the consequences of using specific parameter settings seems to vanish more and more. One example is the somewhat confusing use of the term

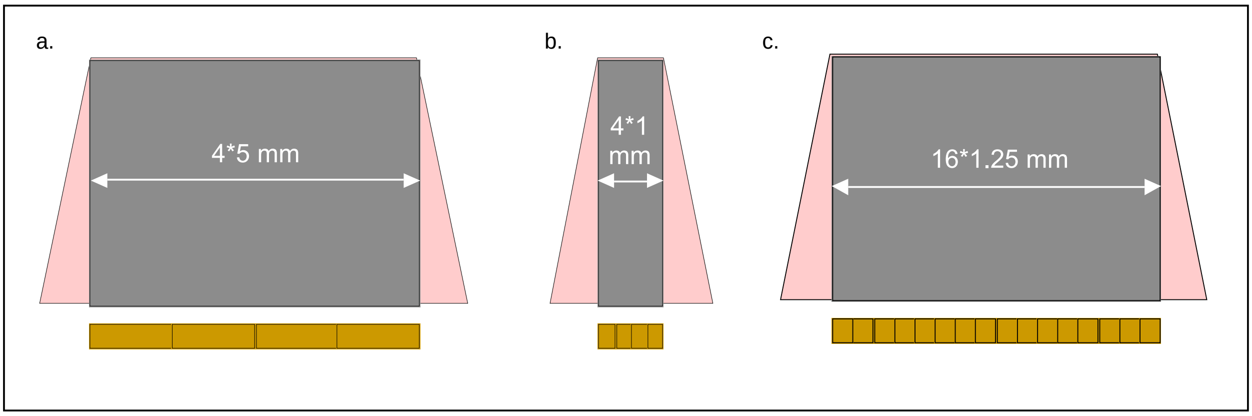

Fig. 3
*Dose increase due to overbeaming for different collimator settings and types of MSCT scanners. For quad-slice scanners with wide collimation (4 * 5 mm; fig. 3a), the increase in dose due to overbeaming is between 10 and 25%, depending on the type of scanner. With narrow collimation (4 * 1 mm; fig. 3b), however, the dose increase amounts to between 40 and 100%, and significantly exceeds the 100% level for sub-millimetre slices. 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).*

pitch. Meanwhile, with the introduction of 16-slice scanners, the majority of CT manufacturers has returned to use the correct, dose-relevant pitch p, instead of the volume pitch p'. The first is given by the ratio of table feed per rotation, TF, and total collimation, N·h, characterised by values in the neighbourhood of one.

Another example is the indication of slice collimation and slice thickness. On some scanners, only the reconstructed slice thickness is displayed, whereas the slice collimation, which is the relevant parameter to with respect to overbeaming, can only be assessed implicitly. On some scanners, the effective slice thickness is stated in spiral scanning mode, whereas others specify the value corresponding to the slice collimation applied only (e.g. 1 mm instead of 1.3 mm).

The automatic adaptation (i.e. increase) of the tube current-time product on selection of a higher pitch on some types of MSCT scanners is a third pitfall. MSCT scanners manufactured by Elscint, Philips and Siemens vary the tube current according to

$$Tube\ \ current\ (mA) \ = \ \frac{mAs\ \ per\ \ image}{Rotation\ \ time\ (s)} \cdot p \qquad (2)$$

By doing so, slice profile width, noise and radiation exposure can be held constant, independent from the pitch selected (FLOHR et al. 2001). Thus image quality is improved at the expense of dose savings (fig. 4). Consequently, mAs settings are expressed in terms of 'mAs per image', 'mAs per slice' or 'effective mAs' on these scanners, whereas electrical mAs is displayed on the consoles of the other two manufacturers.

Toshiba's MSCT scanners ought to employ the same type of noise compensation, but up to now this must be applied intentionally by the user, if regarded as being necessary. On MSCT scanners from GE, however, tube current adaptation is not required since these scanners make use of a two-point z-interpolation, with the benefits and drawbacks already known from SSCT.

If, therefore, use is made of the benefits offered by z-filtering in combination with automatic noise compensation, pitch can no longer serve as a parameter to control radiation exposure. This might be desirable and justifiable from a technical and applicational point of view, but is in contradiction to present experience and therefore requires additional attention. Furthermore, the use of the term 'mAs per image (or slice)' or 'effective' mAs might be misunderstood to mean that everything is as before.

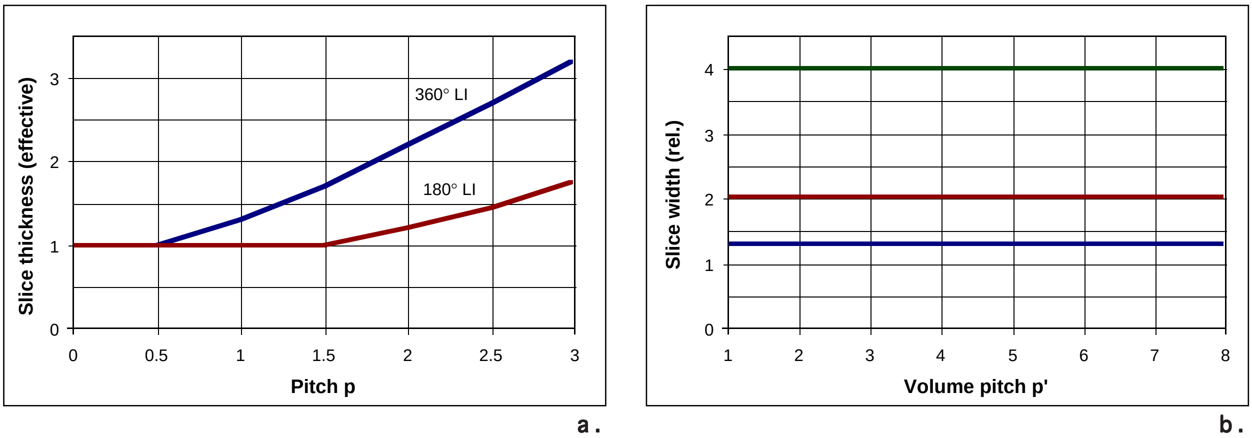

Fig. 4
The dependence of effective slice thickness on the pitch factor in single-slice CT (fig. 4a) and multi-slice CT (fig. 4b). In SSCT, effective slice thickness becomes wider with increasing pitch. For MSCT scanners, which employ z-filtration, effective slice width can be held constant, independent from pitch setting.

3. Current MSCT Practice

3.1 German MSCT Survey 2002

At the beginning of 2002, a nation-wide survey on MSCT practice was conducted in Germany as a joint effort of the German Roentgen Society (DRG), the Federal Office for Radiation Protection (BfS), and the Association of Manufacturers of Electromedical Equipment (ZVEI). At the end of 2001, a total of 207 MSCT scanners were installed in Germany (79 two-slice scanners (duals, most of them former Elscint CT Twin)), 126 four-slice scanners (quads, predominantly Siemens Volume Zoom), and two eight-slice scanners (GE LightSpeed Ultra).

Tab. 1
Types of standard CT examinations considered in both surveys on SSCT practice (in 1999) and MSCT practice (in 2002).

Standard Examination	
Name	**Abbr.**
Routine Brain	BRN
Facial Bones / Sinuses	FB/SIN
Facial Bones + Neck	FB+N
Routine Chest	CHE
Routine Abdomen (tot.)	AB+PE
Routine Pelvis	PE
Liver / Kidneys	LI/KI
Entire Trunk	TRUNK
CTA Thoracic Aorta	ATH
CTA Abdominal Aorta	AAB
Pulmonary Vessels	PV
Osseous Pelvis	OP
Cervical Spine	CSP
Lumbar Spine	LSP

Similar to the nation-wide survey on SSCT practice in 1999 (GALANSKI et al. 2001), the survey was based on questionnaires sent to all users of MSCT scanners. The types of standard CT examinations considered are listed in table 1. As before, the participation rate (55%) and thus the data base (n=113) were excellent. Details of the study design and the methodology used for dose assessment are documented in BRIX et al. 2003. Here, only the most essential results and conclusions shall be considered.

3.2 Overall MSCT Dose Level

The most interesting question is how MSCT exposure compares with 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 was used. The dose descriptors are the effective CTDI, $\mathrm{CTDI}_{\mathrm{eff}}$ (i.e. weighted CTDI divided by pitch, newly also named 'volume CTDI ($\mathrm{CTDI}_{\mathrm{vol}}$)'), and the dose-length product per examination, $\mathrm{DLP}_{\mathrm{w}}$. While $\mathrm{CTDI}_{\mathrm{eff}}$ depends only on the scan protocol settings (tube voltage, tube current, exposure time, slice collimation, pitch), $\mathrm{DLP}_{\mathrm{w}}$ 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. 5. With $\mathrm{CTDI}_{\mathrm{eff}}$ 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 $\mathrm{DLP}_{\mathrm{w}}$ 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.

These results indicate that – contrary to the impression given by the publications cited 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 $\mathrm{DLP}_{\mathrm{w}}$ is presently higher by a factor of almost two.

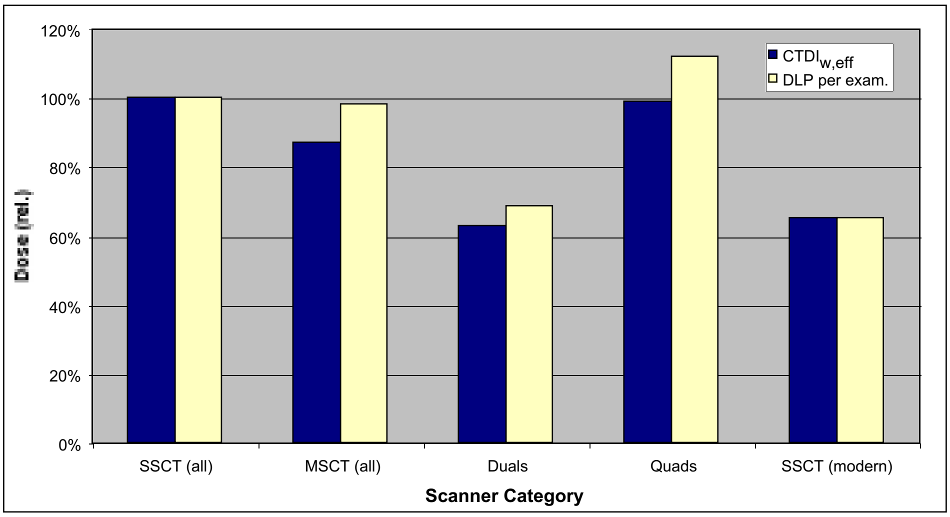

Fig. 5
Comparison of the average dose levels of MSCT and SSCT scanners for local dose (CTDI_{eff}) and integral radiation exposure (DLP_{w}). A relative dose level of 100% refers to the overall average of the 1999 survey on SSCT practice (for details see text).

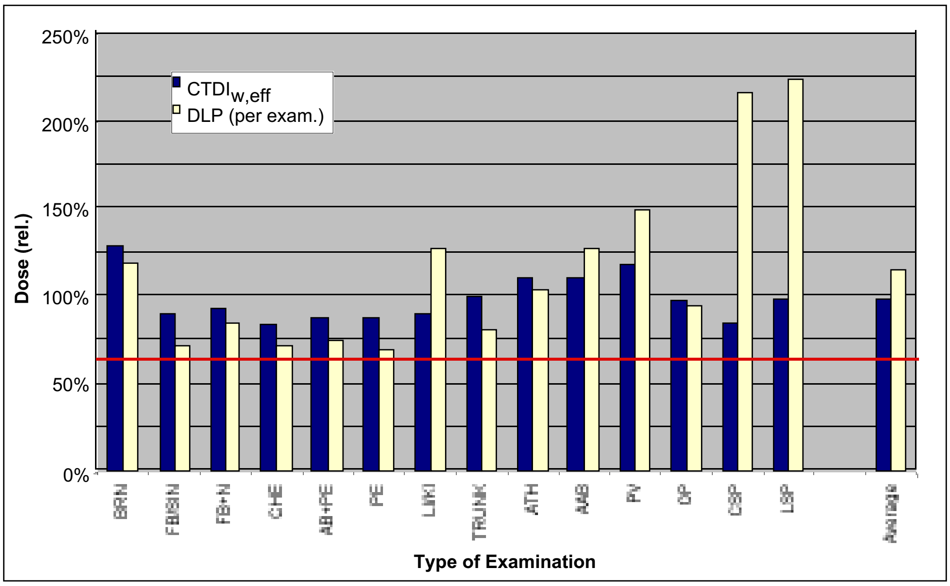

Fig. 6
Relative dose levels of each particular type of examination carried out with quad MSCT scanners (abbreviations see table 1). The most significant dose enhancements are found for standard brain (BRN), liver / kidneys (LI/KI), CTA (ATH, AAB, PV), and spine examinations (CSP, LSP); the red line at 65% refers to the average dose level of modern SSCT and dual MSCT scanners.

3.3 Dose Comparison for Standard Examinations

What are the reasons leading to this excess? A closer look at the relative dose levels of each particular type of examinations provides a first indication (fig. 6). The most significant dose enhancements are found for standard brain, liver / kidneys, CTA and spine examinations. The following circumstances are most likely to explain this increase:

- The majority of participating scanners employs reduced beam filtration in head scanning mode, resulting in increased tube output per mAs. This does not hold for most single-slice scanners.
- In examinations of liver or kidneys, both the average values of scan length and number of scan series are somewhat increased.
- In CTA, the average scan length is also somewhat increased; the main reason, however, is the increase in local dose to compensate for the increased noise owing to the selection of much narrower slices.
- In spine, the average scan length has increased considerably, as now there is a clear preference to scan the entire spine section (cervical spine, lumbar spine) instead of selected segments only.

3.4 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. 7, both the slice collimation used for data acquisition and the reconstructed slice thickness are compared with the slice thickness employed in SSCT scanning. While the unweighted mean of slice thickness amounts to 6.4 mm for SSCT, the average slice collimation employed on

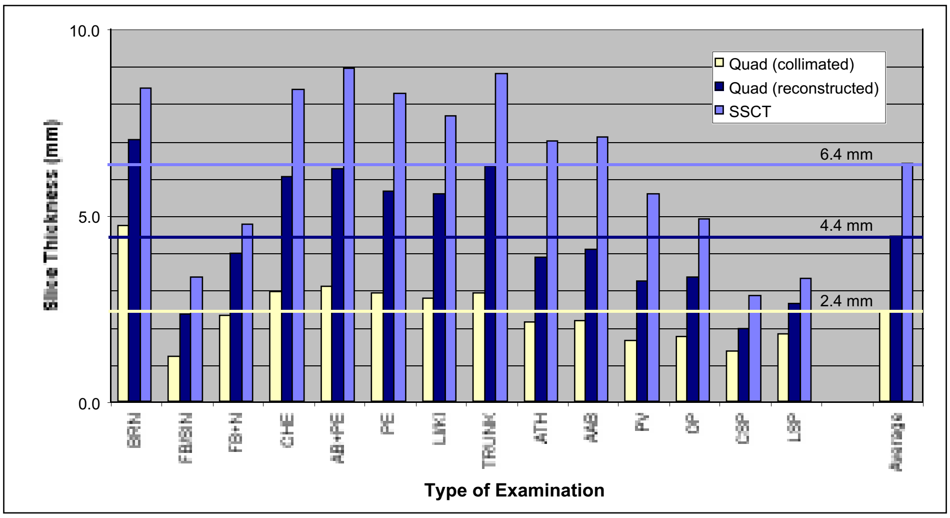

Fig. 7
Collimated and reconstructed slice thickness for SSCT and quad slice MSCT scanners. Both collimated and reconstructed slice thickness used with quad scanners (2.4 and 4.4 mm, respectively) is much lower compared to SSCT practice (6.4 mm, collimated = reconstructed) on average.

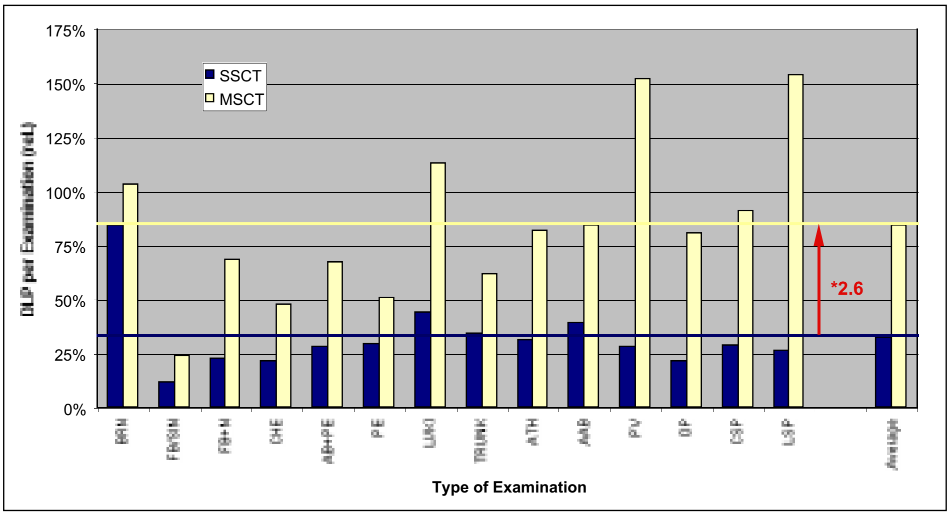

Fig. 8
Example for the comparison of DLP$_w$ per examination, resulting from the protocol settings of the previous SSCT scanner and the new MSCT scanner at one particular institution (100% = average of the 1999 survey). Although MSCT exposure is increased by a factor 2.6 on average, the average dose level, which is 85%, is by no means excessively high.

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 feel the need to compensate for the increased noise associated with thinner slices by increased dose settings.

- Overbeaming: This factor has already been discussed extensively above. 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 that the overbeaming parameter 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 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 increased accordingly [see formula (2)]. This is done automatically on the majority of MSCT scanners installed in Germany. Patient dose is therefore no longer influenced by varying the pitch; 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.

As with the ‘99 SSCT survey, feedback was given to each participant by benchmarking their results against the average values of the previous survey. If an institute has participated in both surveys, a direct comparison of dose values resulting from the protocol settings of their previous SSCT scanner and their new MSCT scanners was also provided. Such a comparison is shown in fig. 8 with the DLP$_w$ per examination used as the dose descriptor. Although MSCT exposure is increased by a factor 2.6 on average, the average dose level of this participant, which is 85%, is by far not excessively high. This kind of ‘comparison’ between perfectly optimised SSCT protocols and imperfectly or non-optimised MSCT protocols is typical for most of the MSCT vs. SSCT studies found in current literature.

4. Suggestions on How to Optimise MSCT Practice

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

4.1 How to Avoid 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 parameter. For 16-slice scanners, overbeaming is much less and therefore requires no special attention.

4.2 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. 9, 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

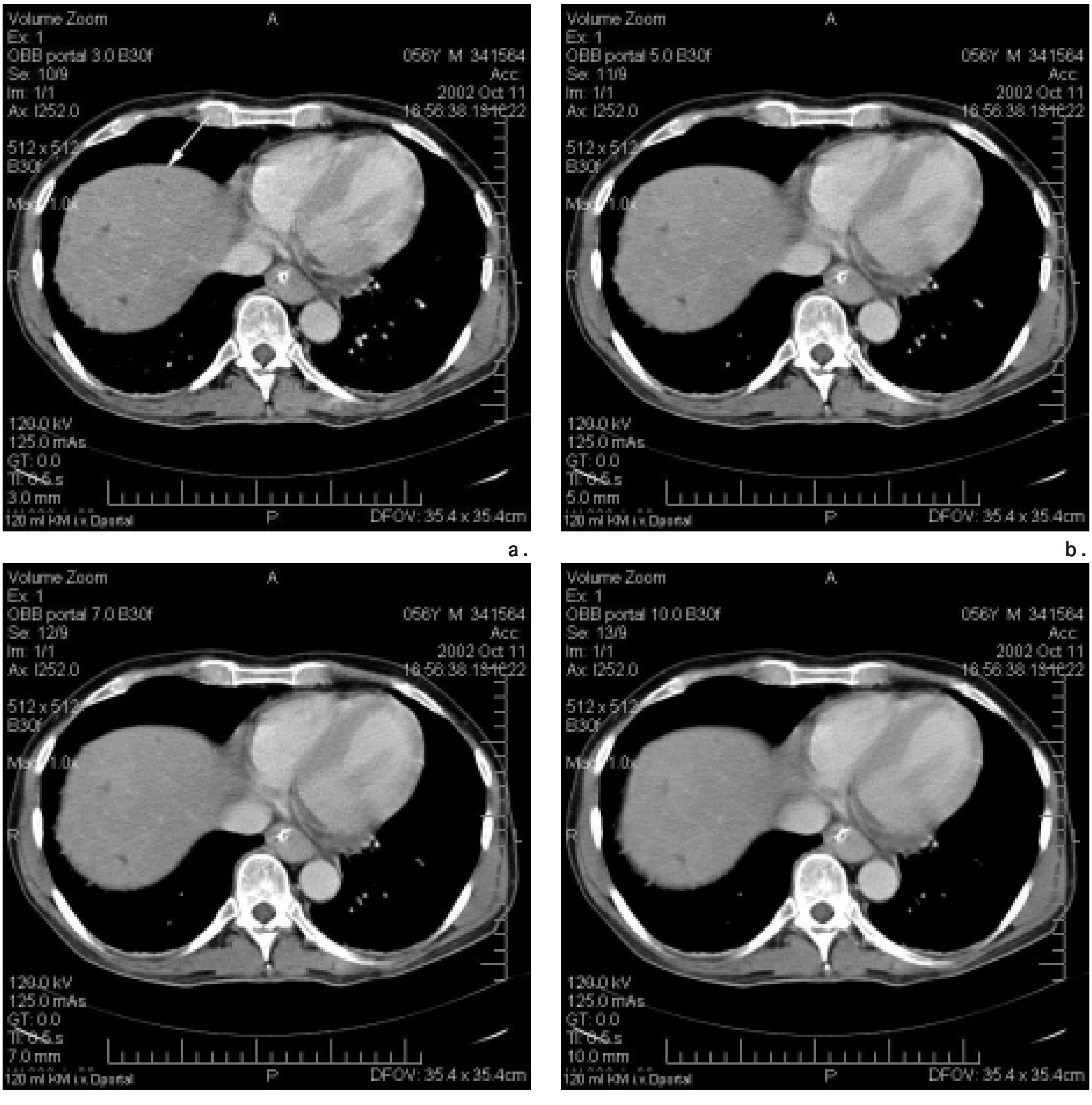

Fig. 9
*MSCT examination of the liver performed on a Siemens Somatom Volume Zoom at 120 kV, 4*2.5 mm slice collimation and 125 mAs_{eff} ($CTDI_{eff}$ = 11 mGy). From the same raw data set, slices of different thickness [3 mm (fig. 9a), 5 mm (fig. 9b), 7 mm (fig. 9c), and 10 mm (fig. 9d)] were reconstructed 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).*

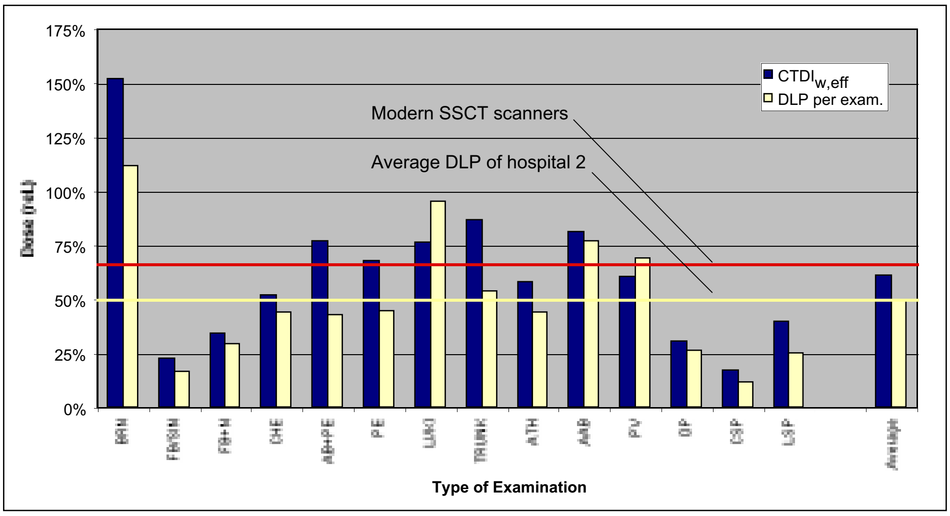

Fig. 10
Benchmarking result for an institution participating in the 2002 MSCT survey. As increased image noise associated with narrow slices is over-compensated by improved contrast due to reduced partial volume effect, dose can be reduced to a level below of that of modern SSCT scanners (i.e. 65%).

making use of thinner slices. An increasing number of MSCT users have already become aware of this principal advantage of MSCT. Thus the dose values resulting from their scan protocols remain at a reasonable level. Such an example is shown in fig. 10.

4.3 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.

4.4 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 (COUNCIL OF THE EUROPEAN UNION 1997), should be established and should become mandatory.

4.5 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. This partially explains the excessively high rate of incorrect questionnaires. 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.

5. Summary

Multi-slice scanners offer specific advantages and penalties for patient exposure. Results from a recent survey on MSCT practice in Germany indicate that dual-slice scanners (which are mainly former Elscint Twin scanners) are used at dose levels comparable with modern SSCT scanners, while dose values resulting from quad-slice scanner protocols are currently significantly, but not dramatically higher. The main causes are: (1) reduced slice thickness, which tempts the users to increase mAs in order to compensate for increased noise, (2) overbeaming due to the avoidance of penumbral effects, which is most pronounced at narrow slice collimation, and (3) reduced transparency of the implications of parameter settings on dose (e.g. pitch, mAs per slice, reduced beam filtration in head scanning mode, etc.).

The key factor to reduce dose to a level comparable to modern single-slice and dual-slice scanners is to appreciate the improved detail contrast achieved with thin slices due to reduced partial volume effect. This over-compensates the drawback of increased noise. Thus at least the same dose level as for modern SSCT scanners should be attainable. New technical means have the potential to further reduce dose to values well below. This will help to balance the impact of increased usage of CT. It should be emphasised, however, that technical means are only a prerequisite, but no guarantee for dose reduction. Appropriate training and guidance, as required in the European directive for radiation protection of the patient, is indispensable.

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