Significance of overbeaming and overranging effects of single- and multi-slice CT scanners

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Abstract

Overbeaming (caused by focal spot pemumbra) and overranging (the elongation of the scan range in spiral scanning) are significant dose-increasing factors for MSCT scanner with 4 and more slices. The characteristic features of 24 scanners have been determined by measurement of the axial dose free-in-air at different collimator settings (overbeaming) and by analysis of the scan protocols at different scan parameter settings (overranging). While overbeaming decreases with an increasing number of slices that are acquired simultanesously, the opposite holds true for overranging. The combination of both effects results in a handicap of between 25 and 50% for scanners with 4 and more slices compared to 1- and 2-slice scanners. Much higher values can be expected with a non-adequate selection of scan parameters and for scanners with unfavourable characteristics.

1 Overbeaming

Overbeaming is the excess dose per rotation that results if focal spot penumbra falls outside the active detector area and is not used for imaging purposes. With single-slice CT, there is no absolute need to exclude the penumbra from imaging. Consequently, most single slice scanners make full use of the entire dose profile. Only at collimator settings below 2 mm, some scanners employ restrictive post patient collimation. With multi-slice CT, a different situation comes up. As more than one active detector channel is used, there is a need to serve all channels equally well. Consequently, penumbra must either totally or partially be excluded from detection. So the detector is 'overbeamed', and a certain portion of the radiation that exposes the patient remains unused (fig. 1).

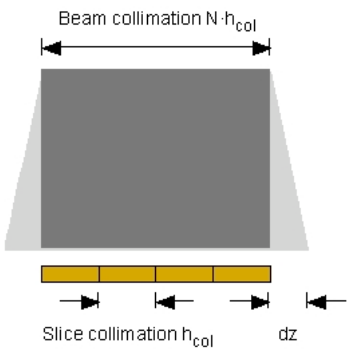

Fig. 1 Dose profile free-in-air for a quad-slice scanner (dark grey: umbra, light grey: penumbra); overbeaming is characterized by the parameter dz.

For a particular type of scanner, overbeaming can be determined by a set of CTDI measurements made free-in air at the axis of rotation for all collimator settings available. It has turned out that the overbeaming characteristics can fairly well be described by a single parameter (the overbeaming parameter dz) that usually represents the combined width of both penumbra triangles (see fig. 1). dz typically amounts to 0 mm for the majority of single-slice scanners, to 1 mm for single-slice scanners with restrictive post-patient collimation and most dual-slice scanners, and to 3 mm for MSCT scanners with four and more slices acquired simultaneously.

Overbeaming itself, i.e. the percentage increase in CTDI due to the unused portion of the dose profile, is then given by

$$\Delta CTDI_{rel} = \left(\frac{N \cdot h_{col} + dz}{N \cdot h_{col}} - 1 \right) \cdot 100 \qquad (1)$$

where N is the number of slices acquired simultaneously and h_{col} is the slice collimation. Overbeaming is largest if dz is large and the beam width N · h_{col} is small. The more slices that can be acquired simultaneously, i.e. the larger the beam width that can be used in conjunction with a small slice collimation h_{col}, the less the excess in dose.

2 Overranging

Overranging is the increase in dose-length product due to the additional rotations at the beginning and at the end of a spiral scan required for data interpolation to reconstruct the first and the last slice of the imaged body region. With single-slice scanners, theory requires that $\Delta n = 1$ additional rotation is usually made in total. For multi-slice scanners, the situation is much less obvious, as will be seen from the results presented below.

Overranging effects can be deduced from the parameters displayed at the operator's console of the scanner and can be verified by dose measurements made free-in-air with the detector of the dosemeter kept stationary at the isocenter. Effects can be expressed both in terms of the additional number Δn of rotations and the increase ΔL in scan length. ΔL primarily depends on two factors: the beam width $N \cdot h_{col}$ and the pitch factor p. This can be fairly well described by a linear relationship

$$\Delta L = (m_{OR} \cdot p + b_{OR}) \cdot N \cdot h_{col} \quad (2)$$

While single-slice scanners behave as expected from theory, the characteristics of typical MSCT scanners differ markedly (see fig. 2). The number Δn of additional rotations is strongly pitch dependent, while $\Delta L/(N \cdot h_{col})$ is almost independent from pitch and amounts to approximately 1.5, i.e. ΔL is typically 1.5 times the total beam width $N \cdot h_{col}$. For most single-slice scanners, m_{OR} and b_{OR} are equal to 2 and –1, respectively. For the majority of MSCT scanners, typical values for m_{OR} and b_{OR} are 1 and 0.5, respectively.

The implications of overranging effects for the radiation exposure to the patient, i.e. the dose-length product DLP, not only depend on ΔL, but also on the length L_{net} of the imaged body region. The percentage increase in DLP is given by

$$\Delta DLP_{rel} = \frac{\Delta L}{L_{net}} \cdot 100 \quad (3)$$

and will be largest if ΔL is large and L_{net} is small.

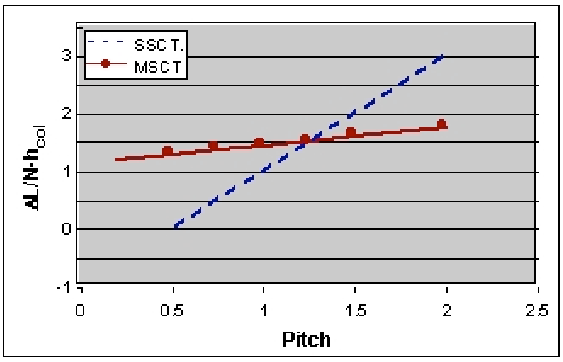

Fig. 2 Overranging characteristics of typical single- (SSCT) and multi-slice (MSCT) scanners.

3 Combined effects

Estimates of the relevance of overranging and overbeaming effects should not refer to extreme situations, but rather to typical scan and examination parameter. Both effects depend on the collimator settings (i.e. beam width), while overranging additionally depends on the pitch and the scan length. So the typical settings found in surveys and in scan protocols recommended by the manufacturers were assumed, and a typical scan length L of 20 cm was taken as a representative value.

In fig. 3, the combination of overbeaming and overranging, i.e. the percentage increase in DLP due to both phenomenons, is shown for each scanner class. For MSCT scanners with N = 4 and above, the increase in DLP is roughly 30% higher than for single- and most dual-slice scanners. Remarkably, the reduction in overbeaming with an increasing N is compensated by the increase in overranging such that the percentage increase in DLP remains almost constant for 4-, 6/8- and 16-slice scanners. The latest generation of 32-, 40- and 64-slice scanners was not included in this study, as only a few of these models were already in use at the point in time when this study was performed, with most of them being test models. For true 64-slice scanners with a beam width of 40 mm, an increase in DLP of typically 30% compared to single- and dual-slice scanners, which is almost due to overranging, is likely to be expected

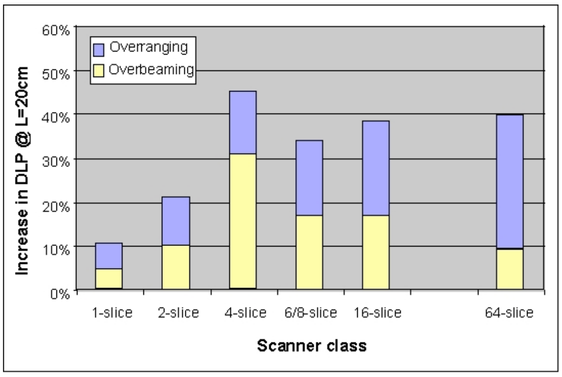

Fig. 3 The percentage increase in DLP from the combination of overbeaming and overranging effects, for 20 cm scan length and parameter settings that are typical for each scanner class.

Much higher values must be anticipated for scanners with unfavourable characteristics and with a non-adequate selection of scan parameters. The latter can easily be avoided by making use of the DLP information that is displayed prior to the scan or by dedicated CT dose software such as CT-Expo that takes both effects into account.