# Artefacts in CT: Recognition and Avoidance

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## Introduction

CT images are inherently more prone to artefacts than conventional radiographs because the image is reconstructed from something in the order of a million independent detector measurements. The reconstruction technique assumes that all these measurements are consistent, so any error of measurement will usually reflect itself as an error in the reconstructed image. The types of artefact that can occur are:

- **Streaking**, generally due to an inconsistency in a single detector measurement
- **Shading**, due a group of channels or views deviating gradually from the true measurement
- **Rings**, due to errors in an individual detector calibration
- **Distortion**, due to helical reconstruction

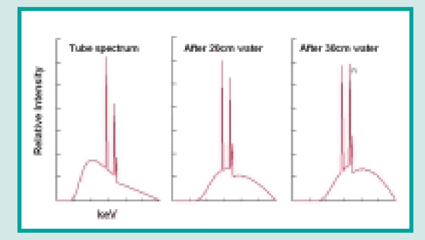
It is possible to group the origins of these artefacts into four categories:

- **Physics based artefacts**, resulting from the physical processes involved in the acquisition of CT data
- **Patient based artefacts**, caused by such factors as patient movement or the presence of metallic materials in or on the patient
- **Scanner based artefacts**, resulting from imperfections in scanner function
- **Helical and multi-slice artefacts**, dependent on the image reconstruction method employed

Good scanner design minimises some types of artefact, and some can be partially corrected for by the scanner's software. There are, however, many instances where careful patient positioning and the optimum selection of scan parameters are the most important factors in avoiding image artefacts.

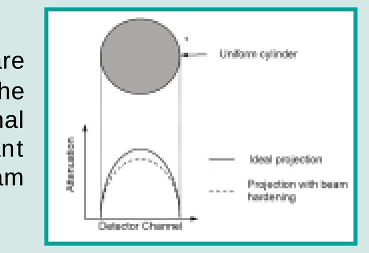
# Physics based artefacts

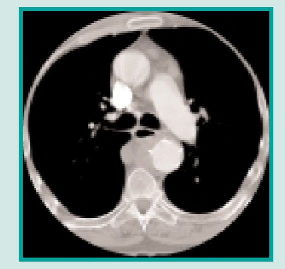
## Beam hardening




An x-ray beam is composed of individual photons with a range of energies. As the beam passes through an object, it becomes harder, i.e. its mean energy increases, because the lower energy photons are absorbed more rapidly than the higher energy photons. Two types of artefact can result from this effect: so-called 'cupping' artefacts and the appearance of dark bands or streaks between dense objects in the image.

**Cupping artefacts**. X-rays passing through the middle portion of a uniform cylindrical phantom are hardened more than those passing though the edges because they are passing though more material. The harder it becomes, the less the beam is attenuated, so when it reaches the detectors it gives a higher signal (corresponding to lower attenuation) than would be expected if it had not been hardened. The resultant attenuation profile therefore differs from the ideal profile that would be obtained if there were no beam hardening. A profile of the CT numbers across the phantom displays a characteristic cupped shape.



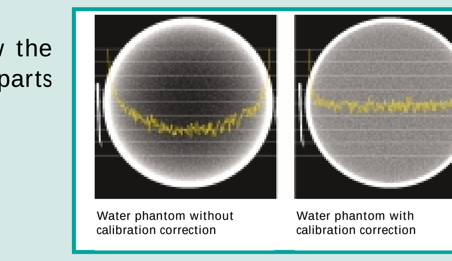



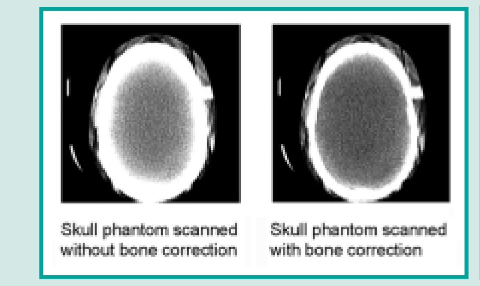
**Streaks and dark bands**. In very heterogeneous cross sections, dark bands or streaks can appear between two dense objects in an image. They occur because the portion of the beam that passes through one of the objects at certain tube positions is hardened less than when it passes through both objects at other tube positions. This type of artefact can occur both in bony regions of the body and in scans where contrast has been used. In this chest scan, the contrast has caused artefacts which might be mistaken for pathology in the nearby aorta.

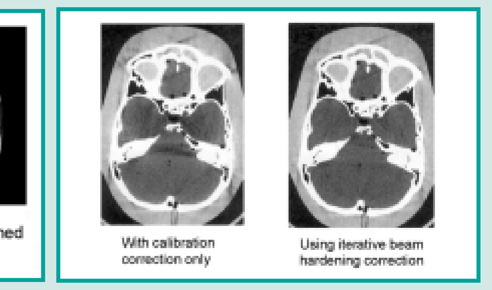
### Built-in features for minimising beam hardening

**Filtration**. A flat piece of attenuating material such as aluminium or copper 'pre-hardens' the beam by filtering out the lower energy components before it passes through the patient. An additional 'bowtie' filter further hardens the edges of the beam which will pass through the thinner parts of the patient.

**Calibration corrections**. Some manufacturers provide phantoms in a range of sizes which allow the detectors to be calibrated with compensation tailored for the beam hardening effects of different parts of the patient. This provides an effective means of minimising cupping artefacts.


Water phantom without calibration correction — Water phantom with calibration correction


Skull phantom scanned without bone correction — Skull phantom scanned with bone correction


With calibration correction only — Using iterative beam hardening correction

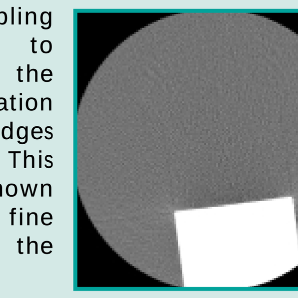
**Beam hardening correction software**. An iterative correction algorithm may be automatically applied when images of bony regions are being reconstructed. This helps minimise blurring of the bone/soft tissue interface in brain scans and also reduces the appearance of dark bands in non-homogeneous cross sections.

### Avoidance of beam hardening by the operator

It is sometimes possible to avoid scanning bony regions, either by means of patient positioning or by tilting the gantry.

## Undersampling

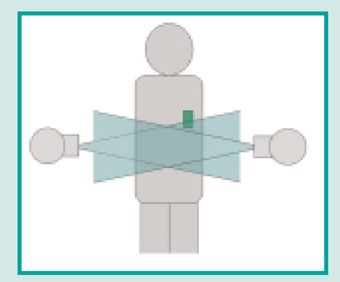
Too coarse a sampling interval leads to misregistration by the computer of information relating to sharp edges and small objects. This leads to an effect known as aliasing, where fine striations appear in the image.



### Avoidance

Aliasing may not have too serious an effect on the diagnostic quality of an image, since the evenly spaced lines do not normally mimic any anatomical structures. However, where resolution of fine detail is important, undersampling artefacts need to be avoided as far as possible by using high resolution techniques such as quarter-detector shift or flying focal spot.

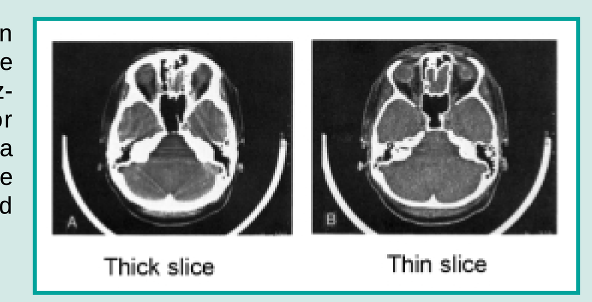
## Partial volume



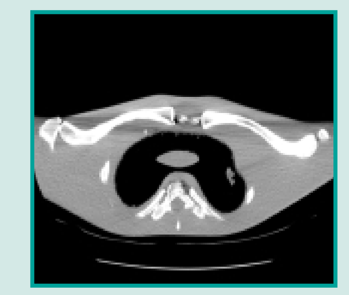
As well as the familiar effect of CT number underestimation for dense objects, partial volume can also cause shading artefacts when the dense objects are off-centre. In this diagram, the divergence of the x-ray beam along the z-axis has been greatly exaggerated to demonstrate how an off-axis object can be within the beam, and therefore 'seen' by the detectors, when the tube is pointing from left to right, but outside the beam, and therefore not seen by the detectors, when the tube is pointing from right to left. The inconsistencies between the views cause artefacts to appear in the image.

### Avoidance

Partial volume artefacts can be expected in images of any part of the body where the anatomy is changing rapidly in the z-direction, for example in the posterior fossa. They can best be avoided by using a thin acquisition slice. To reduce image noise, thicker slices can be reconstructed from the acquired data.


Thick slice — Thin slice

## Photon starvation

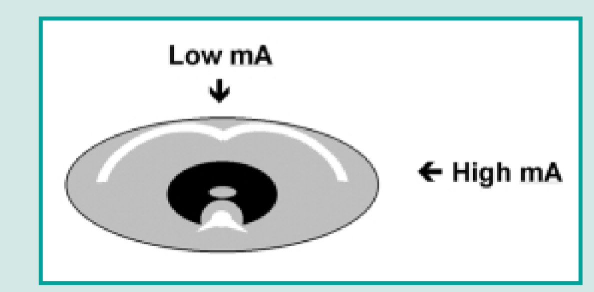


A potential source of serious streaking artefacts is photon starvation, which can occur in highly attenuating areas such as the shoulders. When the beam passes horizontally through the widest part of the patient, insufficient photons reach the detectors and very noisy projections are produced. The noise is magnified when the views are reconstructed, resulting in horizontal streaks in the image.

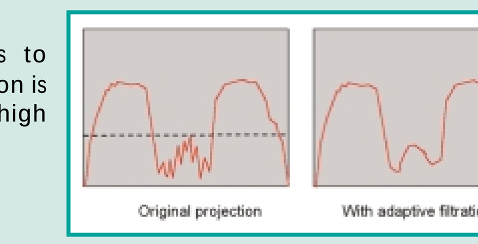
If the tube current is increased for the duration of the scan, the problem of photon starvation will be overcome, but the patient will receive unnecessary dose when the beam is passing through less attenuating parts.

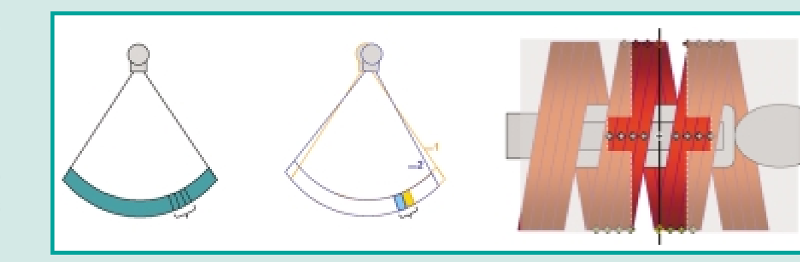
### Manufacturers' techniques for minimising photon starvation

**Automatic tube current modulation.** On some scanner models, a type of mA modulation is incorporated in which the tube current is automatically varied during the course of each rotation. This allows sufficient photons to pass through the widest parts of the patient without unnecessary dose to the narrower parts.



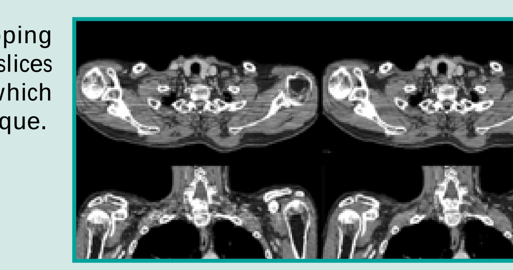

**Adaptive filtration**. Some manufacturers use software corrections to reduce the streaking in photon-starved images. A type of adaptive filtration is used which smoothes each projection only in areas of low signal, i.e. high attenuation, before the image is reconstructed.


Original projection — With adaptive filtration



A multidimensional adaptive filtration technique is currently being developed for use on multi-slice scanners. For the small proportion of projection data which exceeds a selected attenuation threshold, smoothing is carried out between adjacent in-plane detectors and between successive projection angles, whilst the z-filter used in helical reconstruction is broadened for high attenuation projection angles to allow more photons to contribute to the reconstruction.

The group at the Institute of Medical Physics, Erlangen who are developing the technique publish these images, showing the original transaxial slices above and coronal reformations below, to demonstrate the degree to which streaking is reduced but spatial resolution maintained using the technique.


Courtesy: Prof. Kalender, University of Erlangen

# Patient based artefacts

## Metallic materials

The presence of metal objects in the scan field can lead to severe streaking artefacts. They occur because the density of the metal is beyond the normal range that can be handled by the computer, resulting in incomplete profiles.

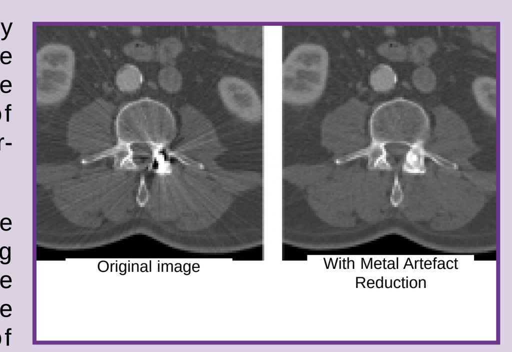
### Avoidance of metal artefacts by the operator

Patients are normally asked to take off removable metal objects such as jewellery before scanning commences. However, with the current fashion for body piercing, this is not always easy! The wearer of this navel ring was allowed to leave it in place, since it was anticipated that any resulting artefacts would be sufficiently distant from the organs of interest as not to cause a serious problem.

For non-removable items, such as dental fillings, prosthetic devices and surgical clips, it is sometimes possible to use gantry angulation to exclude the metal inserts from scans of nearby anatomy.

### Software corrections for metal artefacts

When it is impossible to scan the required anatomy without including metal objects, streaking can be greatly reduced by means of special software corrections. Manufacturers use a variety of interpolation techniques to substitute the over-range values in profiles.


Original image — With Metal Artefact Reduction

The usefulness of metal artefact reduction software is sometimes limited because, although streaking distant from the metal implants is removed, there still remains a loss of detail around the metal/tissue interface, which is often the main area of diagnostic interest.

## Patient motion

Patient motion can cause misregistration artefacts, which appear as shading in the reconstructed image. Steps can be taken to prevent voluntary motion, but some involuntary motion may be unavoidable during body scanning. There are, however, special features on some scanners designed to minimise the resulting artefacts.

### Avoidance of patient motion artefacts by the operator

The use of positioning aids is sufficient to prevent voluntary movement in the majority of patients. In some cases, e.g. paediatrics, however, it is necessary to immobilise the patient by means of sedation.

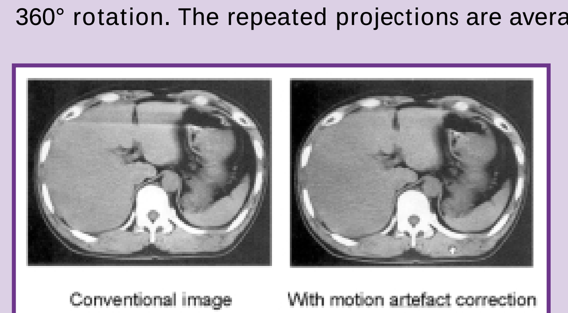
Using as short a scan time as possible helps minimise artefacts when scanning regions prone to movement.

Respiratory motion can be prevented if the patient is able to hold their breath for the duration of the scan.

The sensitivity of motion artefacts depends on the orientation of the motion. It is therefore preferable if the start and end position of the tube is aligned with the primary direction of motion, e.g. vertically above or below a patient undergoing a chest scan.

### Built-in features for minimising motion artefacts

**Overscan.** Some scanner models use overscan for axial body scans, whereby an extra 10% or so is added to the standard 360° rotation. The repeated projections are averaged, which helps reduce motion artefacts.


Conventional image — With motion artefact correction

Courtesy: Shimadzu

**Software corrections.** The maximum discrepancy in detector readings occurs between views obtained towards the beginning and end of a scan. Some scanners have special software corrections which apply reduced weighting to these views to suppress their contribution to the final image.

## Patient dimensions exceeding scan field

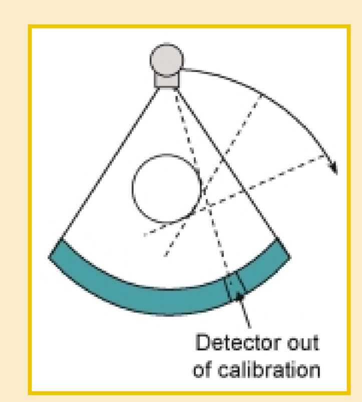
If any portion of the patient lies outside the scan field of view, the computer will have incomplete information relating this portion and streaking artefacts can result. This patient has been scanned with their arms down instead of being raised out of the way of the scan. As the arms are outside the scan field, they are not present in the image, but their presence in some views during scanning has led to such severe artefacts throughout the image as to render it diagnostically unusable.

### Avoidance

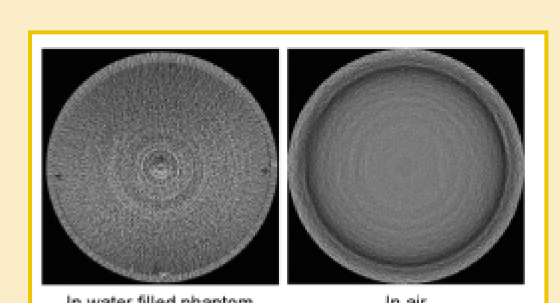
To avoid such artefacts occurring, it is essential to position the patient so that no parts lie outside the scan field. Scanners designed specifically for radiotherapy planning have wider bores and larger scan fields of view than standard scanners and permit greater versatility in patient positioning. They also allow scanning of exceptionally large patients who would not fit within the field of view of standard scanners.

# Scanner based artefacts

## Ring artefacts




If one of the detectors on a third generation (rotate-rotate) scanner is out of calibration, it will give a consistently erroneous reading at each angular position, resulting in a circular artefact. They are more likely to occur on a scanner with solid state detectors, where all the detectors are separate entities, than on an older scanner utilising gas detectors, in which the detector array consists of a single xenon-filled chamber subdivided by electrodes.


In water filled phantom — In air

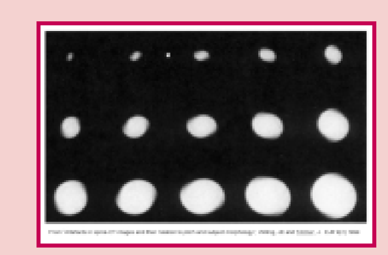
Rings visible in a uniform phantom or in air might not be visible on a clinical image if a wide window is used. Even if they are visible they would rarely be confused with pathology. They can, however, impair the diagnostic quality of an image, and this is particularly likely when central detectors are affected, creating a dark smudge at the centre of the image.

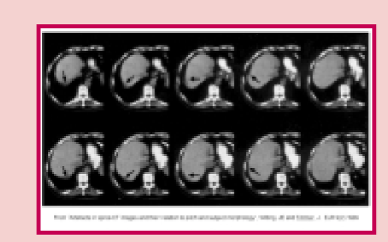
### Avoidance

The presence of circular artefacts in an image is an indication that the detector gain needs re-calibration.

# Helical and multi-slice artefacts

## Helical artefacts in the transverse plane





In general, the same artefacts are seen in helical scanning as in conventional scanning. However, there are additional artefacts that can occur in helical scanning due to the helical interpolation and reconstruction process. The artefacts are a result of rapidly changing structures in the z-direction, e.g. at the top of the skull, and get worse the higher the pitch.

If a helical scan is performed of a cone-shaped phantom lying along the z-axis of the scanner, the resultant transaxial images should appear circular. In fact, however, their shape is distorted because of the weighting function used in the helical interpolation algorithm. For some projection angles, the image is influenced more by contributions from wider parts of the cone in front of the scan plane, while for other projection angles, contributions from narrower parts of the cone behind the scan plane predominate. Thus the orientation of the artefact changes as a function of the tube position at the centre of the image plane.

In clinical images, such as this series of images of the liver, helical artefacts can easily be misinterpreted as pathology.

### Minimisation of helical artefacts

To keep helical artefacts to a minimum, steps must be taken to reduce the effects of variation along the z-axis. This means using, where possible, a pitch of 1 rather than a higher pitch, a 180° rather than a 360° helical interpolator, and thin acquisition slices rather than thick.

Sometimes it is still preferred to use axial rather than helical imaging to avoid helical artefacts e.g. in brain scanning.

## Helical artefacts in multi-slice scanning

Multi-slice scanners are prone to a similar type of transaxial image distortion due to helical interpolation as single-slice scanners. Their severity is reduced by the use of a z-filter helical interpolator instead of a two-point interpolator, especially when the filter width used (i.e. the effective slice thickness) is wider than the detector acquisition width.

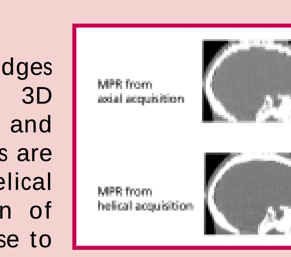
The relationship between helical pitch and the severity of helical artefacts is more complex on multi-slice than on single-slice scanners. Artefacts appear to be slightly reduced when non-integer pitch values, relative to detector acquisition width, are employed. This is because z-axis sampling density is maximised for non-integer pitches.

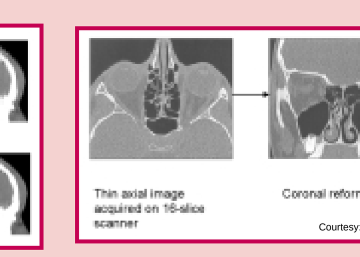
## Multiplanar and 3D reconstructions

Major improvements in multiplanar and 3D reconstructions have come about since the introduction of helical scanning and, to an even greater extent, with multi-slice scanning. The faster speed with which the required volume can be scanned means that the effects of patient motion are much reduced, and the use of narrower acquisition slices and overlapping reconstructed slices leads to sharper edge definition on reformatted images.

### Stair step artefacts

Stair step artefacts appear around the edges of structures in multiplanar and 3D reconstructions when wide collimations and non-overlapping reconstruction intervals are used. They are less severe with helical scanning, which permits reconstruction of overlapping slices without the extra dose to the patient that occurs when overlapping axial scans are performed. Stair-step artefacts are virtually eliminated in multiplanar and 3D reconstructions of thin slice data from today's multi-slice scanners.


MPR from axial acquisition — MPR from helical acquisition


Thin axial image acquired on 16-slice scanner — Coronal reformation

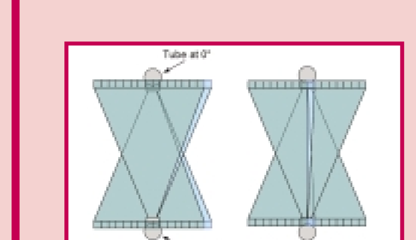
Courtesy: Siemens

### Zebra artefacts

Faint stripes may be apparent in multiplanar and 3D reconstructions of helical data, because the interpolation process gives rise to a degree of noise inhomogeneity along the z-axis. This 'zebra' effect becomes more pronounced away from the axis of rotation because the noise inhomogeneity is worse off-axis.


From: Medical CT and Ultrasound: Current Technology and Applications. AAPM 1995 Summer School

## The cone beam effect




The cone beam effect is a potential source of artefacts on multi-slice scanners. The diagram shows an exaggerated view of the x-ray beam sideways on. As the tube and detectors rotate around the patient (in a plane perpendicular to the diagram), the data collected by each detector corresponds to a volume contained between two cones, instead of the ideal flat plane. Artefacts are more pronounced for the outer detector rows than for the inner ones, where the data collected corresponds more closely to a plane. They occur around off-axis objects, such as this Teflon rod positioned 70 mm from the isocentre at an angle of 60° to the scanner axis.

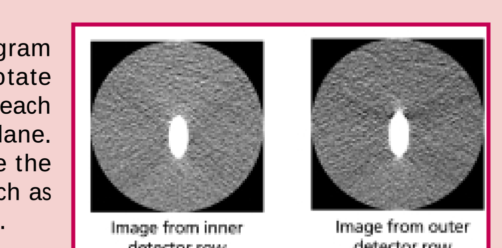
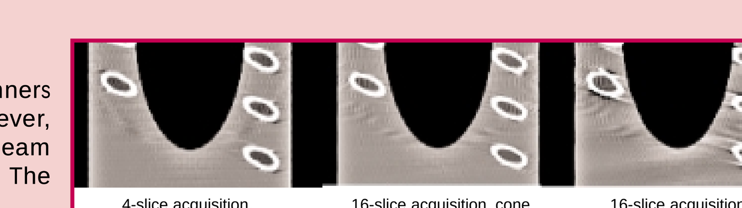


Image from inner detector row — Image from outer detector row

### Manufacturers' techniques for minimising cone beam artefacts

Cone beam effects get worse for thinner slices and for wider cone angles. Thus 16-slice scanners should potentially be more badly affected by artefacts than 4-slice scanners. However, manufacturers have addressed the problem by employing various forms of cone beam reconstruction instead of the standard reconstruction techniques used on 4-slice scanners. The effectiveness of one such technique is demonstrated in this phantom study.


4-slice acquisition, standard reconstruction — 16-slice acquisition, cone beam reconstruction — 16-slice acquisition, standard reconstruction

Courtesy: Siemens