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GE LightSpeed[16]
CT Scanner Technical Evaluation

ImPACT report

MHRA Evaluation Report

MDA 04015

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ImPACT – Imaging Performance Assessment of CT Scanners
An MDA Evaluation Centre

GE LightSpeed^{16}

CT Scanner Technical Evaluation

Assessed at University Hospital of Wales, Cardiff on 15-17 November 2002

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Introduction

■ GE LightSpeed16

The GE LightSpeed16 (Figure 1) is a third generation multi-slice helical CT scanner, featuring a 53 kW generator, 6.3 MHU tube and a fastest gantry rotation time of 0.5 seconds. It is capable of imaging 16 slices per rotation with main collimations of 16 x 0.63 mm and 16 x 1.25 mm. In addition, 2 x 0.63, 1 x 1.25, 1 x 5 and 4 x 3.75, 8 x 1.25 and 8 x 2.5 mm slice modes are also available. It has 24 parallel rows of solid-state detectors, covering 20 mm in the z-direction at the iso-centre. More detailed specifications are given in the next section of this report.

Figure 1, The GE LightSpeed16

The LightSpeed16 is a development of the GE LightSpeed series of scanners. The main difference between the LightSpeed16 and previous models is that the data acquisition system has been upgraded to record sixteen channels of data simultaneously, making this a '16 slice' scanner. In addition, the detector matrix has been re-designed so that the central 8 rows have been divided in two to give 16 x 0.63 mm slices (Figure 2). The image reconstruction technique for helical scanning has changed, and it uses GE's CrossBeam™ and HyperPlane™ algorithms, which are developments of the ASSR (Adaptive Single Slice Re-binning) technique.

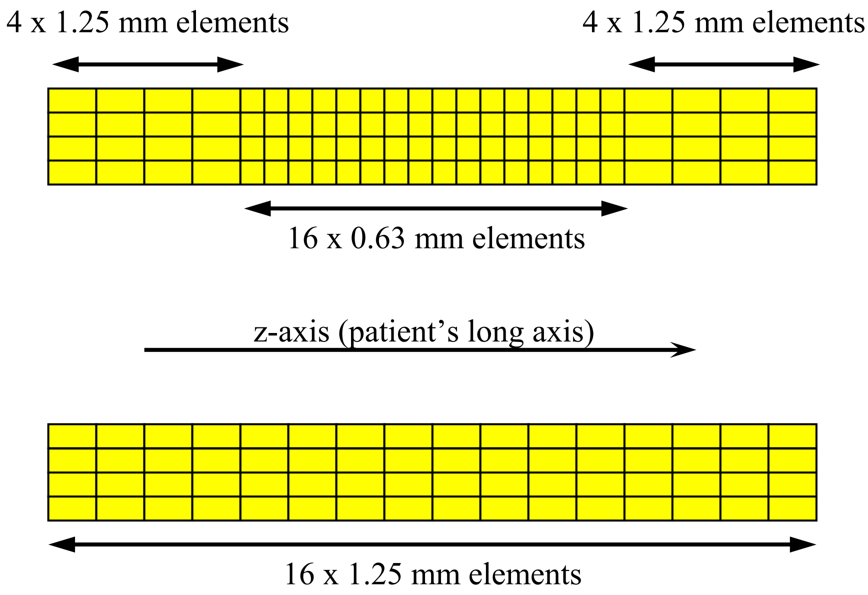

Figure 2. Detector layout for (top) the GE LightSpeed^{16}, and (bottom) the rest of the GE LightSpeed range

The design similarities in the LightSpeed family of scanners are reflected in the results of their assessments, which produce very comparable results. The obvious exception to this occurs when the LightSpeed takes advantage of its sixteen slice scan modes.

■ Assessment Summary

The scanner's dose efficiency figure, Q_2, is above average for head scanning, and average for body scanning, when compared to the four-slice scanners ImPACT has assessed. Scanners with higher Q_2 values will produce images with lower measured noise for a standard patient dose and spatial resolution.

The high contrast spatial resolution of the scanner is typical for a top range system, and close to the average for a range of four slice scanners.

Axial inter-slice variation of image noise and slice thickness is low, although there is a noticeable increase in noise in slices produced by the outer detectors. This is typical for multi-slice scanners. Similarly, the two outer slices are slightly narrower than the other fourteen.

In helical scanning, the image slice width on this scanner depends on helical pitch, and reconstruction method chosen. In general, images acquired with higher pitches and using the 'Plus' reconstruction method are wider than the nominal value. The LightSpeed^{16} offers only four helical pitches when scanning in 16 slice mode, but these cover a good range from 0.56 to 1.75.

Spatial resolution of the scanner along the z-axis in helical scanning is good. This makes possible isotropic imaging, where the resolution is equal in all three dimensions.

Z-axis geometric efficiency on this scanner is improved when compared to four and eight slice LightSpeed scanners. This parameter measures the dose utilisation along the z-axis, and is 83 % for 16 x 0.63 and 97 % for 16 x 1.25 mm collimations. This is an improvement compared to 59 % and 73 % for 4 x 1.25 and 8 x 1.25 mm slices on the LightSpeed Plus and LightSpeed Ultra respectively.

ImPACT's assessment of low contrast detectability on the Catphan phantom showed that 0.3% contrast details of 6 mm in diameter were visible in more than 50 % of images when using a surface dose of 25 mGy, which is similar to previous LightSpeed scanners.

Specifications

Specifications correct as of October 2003.

Scanner Gantry	
Generation	3^{rd}
Aperture (cm)	70
Maximum scan field of view (cm)	50
Nominal slice widths for axial scans (mm)	0.63, 1.25, 2.5, 3.75, 5, 7.5, 10
Couch	
Length and width (cm)	239 x 62 (or 42 just for cradle)
Horizontal movement range (cm)	170
Vertical movement range out of gantry (cm)	51-99
Maximum weight on couch (kg), at specified deflection	180 (±0.25 mm deflection), 205 (±1 mm deflection)
Tube and Generator	
Generator power rating (kW)	53.2
Anode heat capacity (MHU)	6.3
Maximum anode cooling rate (kHU/min)	840
Guaranteed tube life (revolutions)	One year warranty, unlimited rotations
Detection System	
Number of elements along z-axis	24
Effective length of each element at isocentre (mm)	16 x 0.63, 8 x 1.25
Total effective length of detector array at isocentre (mm)	20
Future option for more slices / rotation	None currently
System Start-up and Calibration	
Total start-up time (in routine use)	2 minutes from fully off, 0 from standby
Time to perform a full set of detector calibrations (mins)	20
Recommended frequency for performing full sets of detector calibrations	Once every 24 hours
Scanning	
Scan times (s)	0.3 (partial scan), 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 2.0, 3.0, 4.0
Helical pitches (range and increment, quoted relative to x-ray beam width)	8 slice: Pitch 0.625, 0.875, 1.35 and 1.675 16 slice: Pitch 0.5625, 0.9375, 1.375 and 1.75
Maximum continuous scan time (s)	120
Operator's Console	
Number of monitors at console	2 (1 for patient info and technique selection, the other for image display)
Control methods	Mouse, trackball, keyboard

Image Storage	
Total hard disk storage capacity supplied as standard (Gbytes)	254
Archive options	MOD (images) & DVD (scan data, protocols)
Image Reconstruction	
Time (s) from the start of data acquisition to the appearance of the 30th image of a series:	
(i) standard axial brain scan	27 (with Iterative Bone Option, IBO)
(iii) helical abdomen scan	10
Simultaneous scanning and reconstruction	Yes
3D Reconstruction	
3D reconstruction software	MIPs, MPR (standard* on console and workstation); SSD, 3D Volume Rendering, 3D Virtual Endoscopy (standard* on workstation only)
Additional Facilities	
Independent workstation	Standard*
Contrast injector	Optional*
Contrast media bolus tracking	Standard*
Real time CT (Level 1) and CT fluoroscopy (Level 2) software and hardware	Optional*
Hard-copy imaging device	Optional*
Bone Mineral Densitometry	Optional*
CT Angiography	Standard*
Dental	Optional*
Radiotherapy CT simulation software	Optional*
Prospective ECG-triggered cardiac software	Optional*
Retrospective ECG-gated cardiac software	Optional*
Image Transfer / Connectivity	
DICOM service classes provided by CT console (SCP and SCU)	Storage SCU and SCP, Query/Retrieve SCU, Media service class, Print, Storage Commitment (standard*), Modality Worklist, Performed procedure step (optional*)
DICOM service classes provided by Independent workstation (SCP and SCU)	Storage SCU and SCP, Query/Retrieve SCU, print, media interchange
Speed of scanner / workstation connections to local area networks (Mbits/s)	100

* Items marked as being standard or optional may vary for different purchase requirements

Table 1: LightSpeed[16] specifications

Scanner Performance: Clinical Scans

The scan settings chosen for the six clinical scans, defined in ImPACT Report MDA/98/25, were given by GE for the LightSpeed[16], and said to be representative of protocols in clinical use. Table 2 shows the results obtained using these settings.

$Pitch_d$ is the table increment per rotation divided by the detector thickness. $Pitch_x$ is the table increment per rotation divided by the x-ray beam width.

Results in *italics* are mean results for the following four-slice CT scanners: GE LightSpeed, Philips Mx8000 (formerly Marconi Mx8000), Siemens Volume Zoom and Toshiba Aquilion Multi. Note that the mean z-sensitivity figures result from collimations that may differ from those used for the LightSpeed[16].

Scan	Scan Parameters							Results				
	kV	mA	Time (s)	Slice thicknes (mm) (collimation)	$Pitch_x$ ($Pitch_d$)	Recon FOV (mm)	Recon filter	$CTDI_{vol}$ (mGy)	Z-sens (mm)	Noise (%)	MTF50 (c/cm)	MTF10 (c/cm)
Posterior Fossa	120	160	2	5 (16 x 1.25)		250	Soft	57 *53*	4.9 *4.8*	0.27 *0.35*	3.2 *3.3*	5.9 *6.1*
Helical Head	120	250	1	5 (16 x 1.25)	0.938 (15)	250	Soft	52 *59*	6.1 *4.5*	0.24 *0.36*	3.1 *3.2*	5.7 *6.0*
Standard Brain	120	140	2	5 (16 x 1.25)		250	Soft	50 *53*	4.9 *8.4*	0.29 *0.26*	3.2 *3.2*	5.9 *5.9*
Inner Ear	140	160	1	0.63 (16 x 0.63)		120	Edge	47 *39*	0.54 *2.4*	9.0 *5.5*	9.0 *8.8*	13.7 *17.7*
Helical Inner Ear	140	55	1	0.63 (16 x 0.63)	0.563 (9)	120	Edge	29 *N/A*	0.59 *N/A*	15.1 *N/A*	9.2 *N/A*	13.9 *N/A*
Standard Abdomen	120	275	0.6	5 (16 x 1.25)		380	Std	18 *14*	4.9 *8.4*	2.4 *1.9*	4.0 *3.7*	6.9 *6.4*
Helical Abdomen	120	200	0.6	5 (16 x 1.25)	1.375 (22)	380	Std	9.5 *18*	6.3 *6.1*	3.0 *1.8*	3.9 *3.6*	6.7 *6.3*
Low Noise Spine	120	160	2	2.5 (16 x 2.5)		120	Std	32 *41*	2.5 *2.3*	2.4 *2.3*	4.0 *4.0*	6.7 *6.7*
Hi res spine	120	160	2	2.5 (16 x 2.5)		120	Bone+	32 *40*	2.5 *2.3*	14 *9.8*	9.4 *7.8*	11.6 *11.4*

Table 2: Clinical scan settings and results

Scanner Performance: Dose and Image Quality

In this report, image quality is assessed in terms of objective measurements of image noise, scan plane spatial resolution and imaged slice width. The radiation dose used to acquire these images is given by the $CTDI_{vol}$ measured on the standard head and body phantoms. These values can be combined into a single numerical figure, a Q value, that reflects quantifiable aspects of image quality when taking into account radiation dose. Scanners with higher Q values will produce images with lower noise at a set spatial resolution, when slice thickness and dose are taken into account. Appendix 1 describes the approach in more detail.

Q factors are specific to the phantom used, since noise and dose are phantom dependent. Q values are presented in this section for head and body sized phantoms. A subscript is used to identify the Q value quoted (Q_2), reflecting the way that performance parameters are measured and quoted.

Calculation of Q_2

The imaging parameters used for these scans are chosen to minimise slight variations that occur for different kV, slice thicknesses, scan times and reconstruction algorithm, by using standard values where possible. These are indicated below

Tube voltage: 120 kV or 130 kV when this is the 'standard' operating kV for the scanner.

Collimation: 20 mm, or the closest available setting.

Image width: 5 mm, or the closest available setting

Scan time: as recommended by the manufacturer, sub-second for body scanning and 1 s or greater for head scanning.

Reconstruction algorithm: the algorithm chosen for each scanner is the one that most closely matches the average 'standard' head and body algorithm (MTF_{50} of 3.4 c/cm, MTF_{10} of 6.0 c/cm).

Reconstruction field of view: 250 mm (head) and 380 mm (body).

The mAs setting that would result in a $CTDI_{vol}$ of 50 mGy for head and 15 mGy for body scanning is listed. Z-sensitivity, image noise at 50 or 15 mGy and modulation transfer function (MTF) values are also shown.

Head scanning

Scanner	Recon Filter	mAs for 50mGy	z-sens (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	Q_2
GE LightSpeed[16]	Soft	279	4.9	0.29	3.2	5.9	6.7
Mean		*284*	*4.8*	*0.39*	*3.5*	*6.5*	*5.9*

Table 3: Q_2 value for head scanning

Body scanning

Scanner	Recon Filter	mAs for 15 mGy	z-sens (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	Q_2
GE LightSpeed[16]	Soft	151	9.8	1.6	3.7	6.2	1.8
Mean		*152*	*9.7*	*1.4*	*3.4*	*6.0*	*1.9*

Table 4: Q_2 value for body scanning

Scanner Performance: Image Noise

Variation of image noise with scan parameters

Table 5 shows the variation of image noise for the ImPACT noise phantoms, for a range of scan parameters. The standard parameters are for 120 kV, 135 mA, 2 second scan time, 10 mm collimation, 2 x 5 mm slices, Standard reconstruction filter.

Parameter	Setting	Relative Noise	Adjusted Relative Noise
mA	20	2.84	1.09
	40	1.90	1.03
	80	1.33	1.02
	135	1.00	1.00
	160	0.92	1.00
	220	0.79	1.00
	440	0.55	1.00
Scan Time (s)	0.5	2.20	1.10
	0.6	1.99	1.09
	0.7	1.73	1.02
	0.8	1.58	1.00
	0.9	1.51	1.01
	1	1.42	1.00
	2	1.00	1.00
	3	0.82	1.00
	4	0.71	1.00
Collimation (mm)	2 x 0.63	3.14	1.12
	16 x 0.63	2.78	0.99
	1 x 1.25	2.22	1.11
	8 x 1.25	1.97	0.98
	16 x 1.25	1.93	0.96
	4 x 2.5	1.39	0.98
	8 x 2.5	1.38	0.97
	4 x 3.75	1.15	1.00
	1 x 5	1.01	1.01
	2 x 5	1.00	1.00
	4 x 5	0.97	0.97
	2 x 7.5	0.82	1.00
Focal Spot	Small	1.00	-
	Large	1.00	-

Table 5: Variation of image noise with scan parameters

Each noise value in this section is the average noise from 10 images. Comparing absolute values of image noise between different scanners is meaningless unless the phantoms are identical; for similarly sized phantoms, however, the noise ratios should be similar, therefore relative noise values are quoted. The 'Adjusted Relative Noise' column shows the relative noise when varying each parameter, adjusted for the expected inverse square variation of image noise with mA, scan time and slice width.

Table 6 shows the variation of image noise with reconstruction filter (convolution kernel) in both head and body phantoms.

Parameter	Setting	Relative Noise
Recon. Filter (Head)	Soft	1.00
	Standard	1.25
	Detail	1.72
	Lung	5.48
	Bone	4.99
	Bone+	7.23
	Edge	9.68
Recon. Filter (Body)	Soft	1.00
	Standard	1.19
	Detail	1.17
	Lung	5.52
	Bone	3.26
	Bone+	4.48
	Edge	5.67

Table 6: Variation of image noise with reconstruction filter

Inter-slice noise variation

Table 7 shows the variation of image noise for each slice in a multi-slice axial acquisition. Parameters are 120 kV, 135 mA, 2 s, 16 x 1.25 mm, Soft filter. Noise values in this table are the average of five images. Lower noise is seen for the slices formed from a single 1.25 mm detector row (1-4 and 13-16) than those formed from the combination of 2 x 0.63 rows (5-12). Higher noise values are seen for the outer detector banks, due to the decreased x-ray intensity at the edge of the beam.

Slice number	Noise	Variation from mean (%)
1	0.60	4.2%
2	0.55	-4.5%
3	0.56	-3.3%
4	0.54	-6.3%
5	0.59	2.6%
6	0.60	3.4%
7	0.58	0.1%
8	0.58	0.8%
9	0.57	-1.6%
10	0.59	2.7%
11	0.59	2.6%
12	0.59	2.0%
13	0.57	-1.1%
14	0.56	-2.7%
15	0.56	-3.2%
16	0.60	4.3%
Mean	0.58	-

Table 7: Variation of noise for different slices

Helical image noise

Table 8 shows the image noise measured for helical scans at different pitches, and performed with the two available reconstruction modes, 'Full' and 'Plus'. Scan parameters were 120 kV, 250 mA, 1 s and Soft filter.

Collimation (mm)	Table feed (mm/rotation)	$Pitch_x$ ($Pitch_d$)	Nominal Image Thickness (mm)	Noise (%)
10	5.63	0.562 (9)	0.63 (Full recon)	0.86
10	9.38	0.9375 (15)	0.63 (Full recon)	1.07 *
10	13.75	1.375 (22)	0.63 (Full recon)	0.91
10	17.5	1.75 (28)	0.63 (Full recon)	0.97
10	5.63	0.562 (9)	0.63 (Plus recon)	0.65
10	9.38	0.9375 (15)	0.63 (Plus recon)	0.81 *
10	13.75	1.375 (22)	0.63 (Plus recon)	0.83
10	17.5	1.75 (28)	0.63 (Plus recon)	0.88
20	11.25	0.562 (9)	1.25 (Full recon)	0.61
20	18.75	0.9375 (15)	1.25 (Full recon)	0.82 *
20	27.50	1.375 (22)	1.25 (Full recon)	0.64
20	35.00	1.75 (28)	1.25 (Full recon)	0.68
20	11.25	0.562 (9)	1.25 (Plus recon)	0.45
20	18.75	0.9375 (15)	1.25 (Plus recon)	0.55 *
20	27.50	1.375 (22)	1.25 (Plus recon)	0.57
20	35.00	1.75 (28)	1.25 (Plus recon)	0.60

Table 8: Helical image noise

* The reconstruction algorithm for pitch 0.9375 has changed since the assessment. GE's figures suggest that the FWHM z-sensitivity values marked with an asterisk in Table 8 are now approximately 0.79, 0.75, 0.53 and 0.51 % respectively, from top to bottom of the table. See Appendix 1, the manufacturers' comments section for more details.

Scanner Performance: CT Number and Uniformity

CT number accuracy and uniformity

CT number accuracy and uniformity were assessed in ImPACT's standard water filled head (18.5 cm diameter) and body (34 cm diameter) phantoms. The head phantom has a 3 mm thick bone equivalent shell to mimic a patient's skull. Regions of interest were placed at the centre of the phantom, and 1 cm in from the periphery of the phantom at positions corresponding to North, East, South and West compass points. Tolerance for CT number uniformity is generally 4 HU for head size phantoms and 10 HU for body sized phantoms. Acquisition parameters were 120 kV, 135 mA, 2 s scan time, 4 x 5 mm slice for head and 120 kV, 275 mA, 0.6 s scan time, 4 x 5 mm slices for body.

Position	CT Number	Difference from centre (HU)
Centre	0.40	
N	1.73	1.33
E	1.30	0.90
S	1.74	1.34
W	1.77	1.36

Table 9: CT number accuracy and uniformity for head phantom

Position	CT Number	Difference from centre (HU)
Centre	-0.80	
N	3.84	4.65
E	3.73	4.54
S	4.11	4.91
W	4.25	5.05

Table 10: CT number accuracy and uniformity for body phantom

Scanner Performance: Spatial Resolution

Variation of spatial resolution with scan parameters

Table 11 shows the variation of spatial resolution with scan parameters, in terms of MTF_{50} and MTF_{10}, the frequencies corresponding to the 50% and 10% modulation transfer function values respectively (in line pairs per cm).

Scan parameters for head scans are 120 kV, 170 mA, 2 second scan time, 2 x 5 mm slice, Standard reconstruction filter, 250 mm field of view. For body scanning, 120 kV, 135 mA, 0.6 second scan time, 1 x 10 mm collimation, Standard reconstruction filter and a field of view of 380 mm are used.

Parameter	Setting	MTF_{50} (c/cm)	MTF_{10} (c/cm)
Recon. Filter (Head, Small Focus)	Soft	3.2	5.9
	Standard	3.5	6.6
	Detail	3.9	8.1
	Lung	7.3	8.3
	Bone	7.2	10.9
	Bone+	9.2	11.3
	Edge	8.5	13.1
Recon. Filter (Body)	Soft	3.7	6.2
	Standard	4.0	6.9
	Detail	4.0	7.0
	Lung	7.6	8.4
	Bone	7.2	9.4
	Bone+	8.1	9.8
	Edge	9.1	11.0
Scan Time (s)	0.5	3.5	6.8
	0.6	3.5	6.7
	0.7	3.6	6.6
	0.8	3.6	6.6
	0.9	3.6	6.6
	1	3.6	6.6
	2	3.6	6.6
	3	3.5	6.6
	4	3.6	6.6
Focal Spot	Small	3.5	6.6
	Large	3.4	6.4
Scan Type	Axial	3.5	6.6
	Helical	3.5	6.5

Table 11: Variation of spatial resolution with scan parameters

Spatial resolution and image noise

Figure 3 and Figure 4 show image noise and spatial resolution values for different reconstruction filters, listed below, in head and body scanning respectively. Head scan conditions are 120 kV, 2 s scan time, 4 x 5 mm collimation and 140 mAs, which results in a $CTDI_w$ of 50 mGy. Body scan conditions are 120 kV, 210 mA, 1 s scan time, 4 x 5 mm collimation and 137 mAs, resulting in a $CTDI_w$ of 15 mGy. Spatial resolution is characterised by the average of the MTF_{50} and MTF_{10} values.

Filters used for both head and body scanning are soft, standard, detail, lung, bone, bone+ and edge.

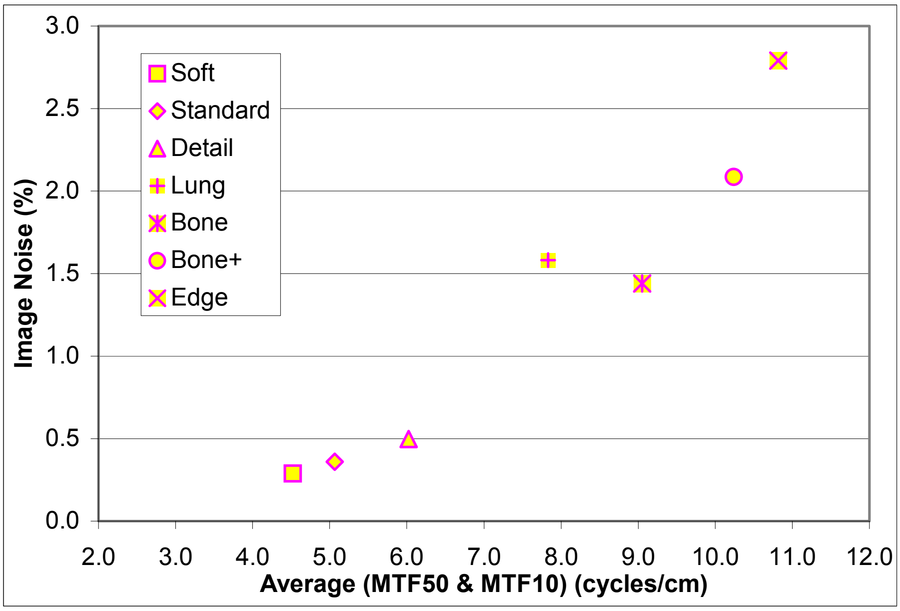

Figure 3: Image noise and spatial resolution for head scanning, for a $CTDI_w$ of 50 mGy

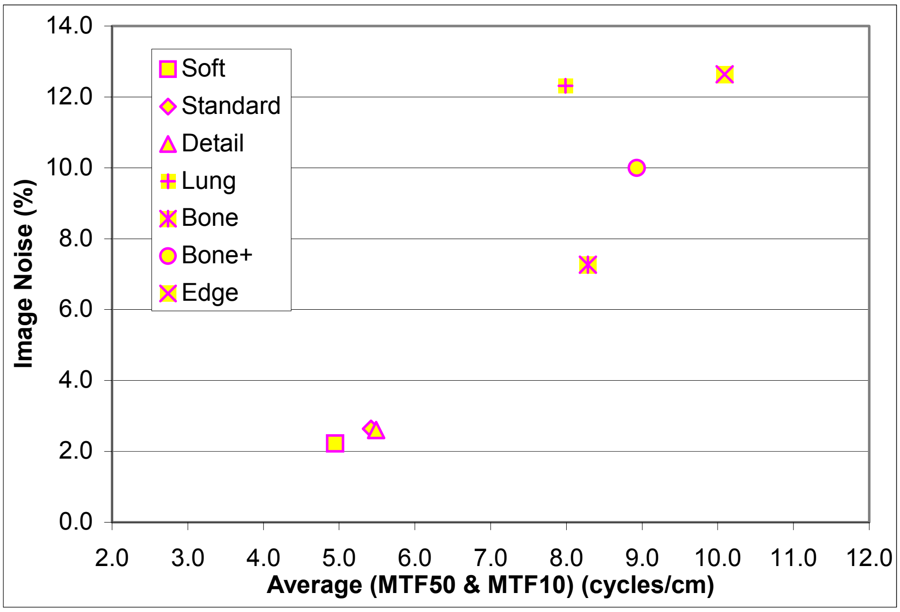

Figure 4: Image noise and spatial resolution for body scanning, for a $CTDI_w$ of 15 mGy

■ Limiting resolution and comparison with GE data

Table 12 shows the limiting resolution as measured by ImPACT on the LightSpeed[16], and quoted by GE in the product data sheet. There is good agreement between the two values. ImPACT data was acquired at 120 kV, 160 mA, 1 s scan time, 8 x 1.25 mm slice, Edge algorithm 120 mm FOV. GE does not quote acquisition conditions, but state that the Edge algorithm was used.

	GE (c/cm)	ImPACT (c/cm)
MTF_{50}	8.5	9.0
MTF_{10}	13.0	13.7
MTF_0 / MTF_2	15.4	16.1

Table 12: Comparison of ImPACT and GE limiting resolution values

For comparison, the mean limiting resolution values for a range of four slice scanners are 11.1 c/cm and 16.6 c/cm for MTF_{50} and MTF_{10}. Scanners included in this mean figure are: GE LightSpeed Plus, Philips Mx8000, Siemens Volume Zoom and Toshiba Aquilion Multi.

Scanner Performance: Slice Width Characteristics

■ Imaged slice width

Slice widths of 2.5 mm and above measured using inclined aluminium plates in water filled phantom. 0.63 and 1.25 mm slices were measured using the ImPACT thin slice test tool, which uses thinner plates at a narrow angle for improved accuracy.

Nominal Slice (mm)	Slice Width, Small Focus (mm)	Slice Width, Large Focus (mm)
2 x 0.63	0.49	0.55
16 x 0.63	0.54	0.60
1 x 1.25	1.04	1.10
8 x 1.25	1.16	1.21
16 x 1.25	1.14	1.17
4 x 2.5	2.5	2.5
8 x 2.5	2.5	2.5
4 x 3.75	3.5	3.5
1 x 5	5.0	5.0
4 x 5	4.9	4.9
2 x 7.5	7.3	7.2
2 x 10	9.8	9.7

Table 13: Imaged slice width

Inter-slice imaged slice thickness variation

Table 14 shows the measured slice thickness at the isocentre for each of the 16 x 1.25 mm slices. Decreased slice thickness for each of the outer slices (1 and 16) is shown.

Slice number	Z-sensitivity (mm)	Variation from mean (%)
1	1.03	-9.5%
2	1.14	0.0%
3	1.16	1.7%
4	1.15	0.8%
5	1.18	3.7%
6	1.17	2.7%
7	1.16	1.9%
8	1.15	0.8%
9	1.16	1.7%
10	1.15	0.6%
11	1.17	2.1%
12	1.17	2.7%
13	1.13	-0.7%
14	1.15	0.6%
15	1.13	-0.6%
16	1.04	-8.5%
Mean	1.14	-

Table 14: Inter-slice imaged slice thickness variation

Dose profiles

Measured using radiotherapy verification film at the centre of the field of view, with a rotating tube. Small focal spot was used. Dose profile width is characterised by the full width at half maximum (FWHM) of the dose profile along the z-axis, as measured using a scanning densitometer.

Total Collimation (mm)	Irradiated FWHM (mm)	Ratio (Irradiated:Nominal)
1.25	2.0	1.59
5	7.4	1.48
10	11.8	1.18
15	16.7	1.11
20	20.1	1.00

Table 15: Irradiated slice thickness

Z-axis geometric efficiency

Geometric efficiency is a measure of x-ray dose utilisation along the z-axis. ImPACT now uses the geometric efficiency figure as specified by the IEC CT safety standard, 60601-2-44 Ed.2 (2001) Amendment 1 (2003). This defines geometric efficiency as the ratio of the integral of the dose profile falling within the nominal detector width to the integral of the dose profile along its total length.

Total x-ray detector width (mm)	Geometric Efficiency
1.25	54%
5	66%
10	83%
15	89%
20	97%

Table 16: Geometric efficiency

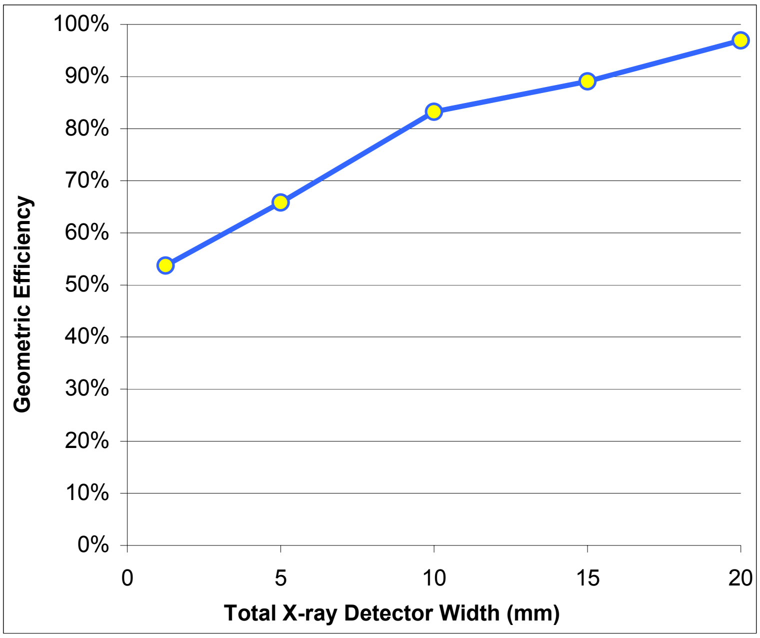

Figure 5: Geometric efficiency

■ Helical z-sensitivity

Measured using a 6 mm diameter, 0.1 mm thick tungsten disc. Scan parameters 120 kV, 100 mA (small focus), 2 s scan time, 4 x 5 mm collimation and 5 mm nominal slice width.

The LightSpeed[16] has 4 helical pitches available. These are 0.562, 0.938, 1.375 and 1.75 when expressed as $Pitch_x$, the ratio of the table feed to the collimated beam thickness (or 9, 15, 22 and 28 when expressed as $Pitch_d$, the ratio of the table feed to the detector group thickness). There are two helical reconstruction modes, known as 'Full' and 'Plus' resulting in slices that are narrower and wider respectively.

Collimation (mm)	Table feed (mm/rotation)	$Pitch_x$ ($Pitch_d$)	Nominal Image Thickness (mm)	Z Sensitivity (FWHM) (mm)
10	5.63	0.562 (9)	0.63 (Full)	0.59
10	5.63	0.562 (9)	0.63 (Plus)	0.74
10	9.38	0.9375 (15)	0.63 (Plus)	0.72 *
10	13.75	1.375 (22)	0.63 (Plus)	0.92
10	17.5	1.75 (28)	0.63 (Plus)	0.93
20	11.25	0.562 (9)	1.25 (Full)	1.27
20	18.75	0.9375 (15)	1.25 (Full)	1.25 *
20	27.5	1.375 (22)	1.25 (Full)	1.62
20	35	1.75 (28)	1.25 (Full)	1.60
20	11.25	0.562 (9)	1.25 (Plus)	1.53
20	18.75	0.9375 (15)	1.25 (Plus)	1.53 *
20	27.5	1.375 (22)	1.25 (Plus)	1.91
20	35	1.75 (28)	1.25 (Plus)	1.92
10	13.75	1.375 (22)	5 (Plus)	6.13
20	18.75	0.9375 (15)	5 (Plus)	6.11 *
20	27.5	1.375 (22)	5 (Plus)	6.27
20	27.5	1.375 (22)	5 (Full)	5.17

Table 17: Helical z-sensitivity

* The reconstruction algorithm for pitch 0.9375 has changed since the assessment. GE's figures suggest that the FWHM z-sensitivity values marked with an asterisk in Table 17 are now approximately 0.93, 1.57, 1.84 and 6.11 mm respectively, from top to bottom of the table. See Appendix 1, the manufacturers' comments section for more details.

■ Limiting resolution along the z-axis

The spatial resolution along the z-axis was measured using the data from the helical z-sensitivity data. The limiting resolution is achieved using 10 mm collimation, 0.562 pitch and 0.63 nominal image thickness. The MTF_{50} and MTF_{10} values can be compared to the average for four 16 slice scanners of 5.2 and 10.4 c/cm respectively.

z-sensitivity (mm)	MTF50 (c/cm)	MTF10 (c/cm)
0.59	7.1	14.0

Figure 6: Limiting resolution in the z-axis

Scanner Performance: Dose

■ $CTDI_{100}$ in air

Standard parameters are 120 kV, 135 mA, 2 second scan time, 10 mm collimation, small scan FOV, small focal spot.

kV	$CTDI_{100}$ (Head) (mGy/100mAs)	$CTDI_{100}$ (Body) (mGy/100mAs)
80	13.0	10.7
100	21.9	19.9
120	32.2	29.3
140	43.9	40.0

Table 18: CTDI in air

Parameter	Setting	Relative $CTDI_{100}$
Focal Spot	Small	1.00
	Large	1.10
Total collimation (mm)	1.25	1.31
	5	1.26
	10	1.00
	15	0.94
	20	0.86
Scan Time (s)	0.5	1.01
	0.6	1.01
	0.7	1.01
	0.8	1.01
	0.9	1.01
	1.0	1.01
	2.0	1.00
	3.0	1.00
	4.0	1.01
Helical scanning (adjusted for pitch)	Axial	1.00
	Helical	1.01

Table 19: Variation of CTDI in air with scan parameters

■ $CTDI_{100}$ in Perspex head phantom

For 120 mA, 2 s gantry rotation time, 10 mm collimation, small scan FOV.

kV	$CTDI_{Centre}$ (mGy/100mAs)	$CTDI_{Periphery}$ (mGy/100mAs)	$CTDI_{W}$ (mGy/100mAs)
80	7.1	7.6	7.4
100	13.4	13.6	13.6
120	21.1	20.8	20.9
140	29.7	29.0	29.2

Table 20: CTDI in Perspex head phantom

■ $CTDI_{100}$ in Perspex body phantom

For 120 mA, 2 second gantry rotation time, 10 mm collimation, large scan FOV.

kV	$CTDI_{Centre}$ (mGy/100mAs)	$CTDI_{Periphery}$ (mGy/100mAs)	$CTDI_{W}$ (mGy/100mAs)
80	1.7	3.8	3.1
100	4.2	8.1	6.8
120	7.2	13.8	11.6
140	10.8	18.6	16.0

Table 21: CTDI in Perspex body phantom

■ Comparison with GE's values

The standard GE quoted CTDI value is for 20mm collimation, therefore ImPACT's measured CTDI in Table 20 and Table 21 have been corrected to take account of this.

Phantom	ImPACT $CTDI_{100}$ (mGy/100mAs)	GE $CTDI_{100}$ (mGy/100mAs)	Ratio ImPACT:GE
Head, centre	18.0	18.7	0.96
Head, periphery	17.8	17.9	1.00
Body, centre	6.2	5.4	1.14
Body, periphery	11.8	11.2	1.05

Table 22: Comparison between ImPACT and GE's CTDI values

Low Contrast Detectability

Low contrast detail detectability

The system was tested with a Catphan 500 phantom for low contrast detail detectability.

ImPACT test low contrast detectability on a 20 cm diameter Catphan, using a surface dose that is as close to 25 mGy as the scanner can supply. Images are reconstructed using the manufacturer's recommended algorithm. For the LightSpeed[16], exposure parameters for ImPACT were 120 kV, 200 mAs, 2 second rotation, 20 mm collimation, 10 mm slice thickness, 250 mm FOV, Standard algorithm. Three observers read 20 images. Details were judged to be visible when they were seen in 50% or more of the total number of images viewed.

	Smallest visible detail (mm)	Nominal Contrast	Surface dose (mGy)
ImPACT (Visual)	6	0.3%	24.7
GE (Statistical)	5	0.3%	13.3

Table 23: Catphan low contrast detail

GE's figure uses their 'statistical' analysis of low contrast performance, which results in a 5 mm detail size at 0.3 % contrast at 13.3 mGy with a 95% confidence level using an 8 inch Catphan, 10 mm slice thickness and 100 mAs exposure.

Appendix 1: Manufacturer's Comments

GE Medical Systems
General Electric Company
3200 N. Grandview Boulevard
Waukesha, Wi, 53188

January 8, 2004

Nicholas Keat
Physicist
St. George's Hospital
London SW17 0QT
United Kingdom
Tel: 020 8725 1048/ 3366
Fax: 077 5383 6367

Dear Nick:

Thank you for giving GEMS an opportunity to review GE Lightspeed16 Advantage, CT Scanner Technical Evaluation, Draft for Manufacturer's Comment. GEMS would appreciate consideration of our comments and concerns prior to final release.

In summary our comments are:

1. The title of this report includes a reference to the GE Lightspeed16 Advantage CT system. GE has decided to name this model as the GE LightSpeed^{16} CT Scanner.

2. Page 3, first paragraph – Please include a reference to the available 8-slice scanning modes, 8 x 1.25mm and 8 x 2.5mm.

3. Page 3, last paragraph – Please include a reference to the GEMS *CrossBeam* reconstruction algorithm in conjuction with the mention of *HyperPlane*. Since these terms are trademarked, we would appreciate the addition of the ™ symbol following each reference.

4. Image Reconstruction, page 7 - Please edit the Reconstruction Times table to include our XTream Console data:

   Time(s) from the start of data acquisition (X-ray on) to the appearance of the 30th image of a series:

(i) standard brain scan	27 s
(ii) axial spine scan	14 s
(iii) helical abdomen scan	10 s

5. Image Transfer/ Connectivity, page 7 - Please add Storage Commitment SCU to the list of DICOM Services on the Main Console.

6. Inter-slice noise variation, page 11 – While appreciating the table of Noise by Slice Number we are uncertain of the value of the Variation from the Mean column. GEMS suggests deletion of this column in the table.

7. Helical Image Noise, page 12 & Helical z-sensitivity, page 20 - The reconstruction algorithm for pitch .9375 has been changed since your team evaluated the LightSpeed16 scanner at Cardiff. We have measured Image Thickness and Noise for the 10mm and 20mm collimations in both Full and Plus modes for the updated algorithms for all pitches. We would appreciate your inclusion of our measured data in place of the data collected during the ImPACT experiments of 15-17 November, 2002.

mode	fwhm/fwtm	noise
16x0.625_P09_0.63mm_full_ssp_data.txt	0.596552/1.10107	10.27
16x0.625_P15_0.63mm_full_ssp_data.txt	0.799519/1.48716	9.7
16x0.625_P22_0.63mm_full_ssp_data.txt	0.828180/1.49450	11.39
16x0.625_P28_0.63mm_full_ssp_data.txt	0.811685/1.45117	12.44
16x0.625_P09_0.63mm_plus_ssp_data.txt	0.753282/1.41805	8.04
16x0.625_P15_0.63mm_plus_ssp_data.txt	0.930547/1.70718	9.14
16x0.625_P22_0.63mm_plus_ssp_data.txt	0.950131/1.72385	9.84
16x0.625_P28_0.63mm_plus_ssp_data.txt	0.929890/1.69564	10.41
16x1.25_P09_01.25mm_full_ssp_data.txt	1.31342/2.32775	6.94
16x1.25_P15_01.25mm_full_ssp_data.txt	1.57372/2.81704	6.44
16x1.25_P22_01.25mm_full_ssp_data.txt	1.59890/2.85254	8.45
16x1.25_P28_01.25mm_full_ssp_data.txt	1.62209/2.90190	8.4
16x1.25_P09_01.25mm_plus_ssp_data.txt	1.57347/2.84693	5.38
16x1.25_P15_01.25mm_plus_ssp_data.txt	1.84368/3.29612	6.21
16x1.25_P22_01.25mm_plus_ssp_data.txt	1.86969/3.31629	7.05
16x1.25_P28_01.25mm_plus_ssp_data.txt	1.91287/3.35776	6.95
16x0.625_P22_5.00mm_plus_ssp_data.txt	5.93114/9.02995	(Impact not reported)
16x0.625_P15_5.00mm_plus_ssp_data.txt	6.03687/9.20907	(Impact not reported)
16x1.25_P22_05.00mm_plus_ssp_data.txt	6.00170/9.54092	(Impact not reported)
16x1.25_P22_05.00mm_full_ssp_data.txt	5.09053/8.19757	(Impact not reported)

In our table pitch P09=IEC pitch .5625, P15=IEC pitch .9375, P22=IEC pitch 1.375 and P28=IEC pitch 1.75

8. CTDI measurement comparison, page 22 – While GEMS publishes a table of measured CTDI values at 20mm collimation, there are look-up tables included in the GEMS Technical Reference Manual that allow the user to scale the CTDI for a number of variables inlcuding other collimation lengths.

Thank you for this opportunity to review the draft version of your report. Please contact one of us if you have any questions regarding this reply.

Sincerely,

Thomas J. Myers, Piero Simoni and Thomas L. Toth

ImPACT thanks GE for their comments, and has updated the report to reflect comments 1-5 and 8 in the response from GE.

No changes have been made as a result of comment 6, as it is felt that the variation from the mean column gives a useful guide to the relative, rather than absolute differences in image noise from each slice. This is also useful as the absolute values of image noise are unlikely to be duplicated if the system is tested using a different phantom, but the relative values should be approximately the same.

In reply to comment 7, the relevant sections have been modified to include a comment that the reconstruction algorithm was different. They also give estimates of noise and z-sensitivity with the different algorithm, and to look to this appendix for more details.

Appendix 2: Image Quality Assessment and Q

Image noise, scan plane spatial resolution and imaged slice width are fundamental parameters describing the amount of object information retrievable from an image, or its image quality. Radiation dose can be regarded as a 'cost' of this information. In general, it is meaningless to quote any one of these measurements without reference to the others.

It is possible to incorporate dose, noise, spatial resolution and slice width into one number, using formulae derived from the relationships between image quality and dose. Figures of merit such as this can take a number of forms depending on how the various parameters are measured and quoted. ImPACT use the Q_2 value, whose formula and methods of measurement are given below.

High Q_2 values result from CT scanners that produce images with lower noise at a set spatial resolution, when dose and image width are taken into account.

The parameters used in Q are standard imaging performance parameters. However it should be noted that the quantification of perceived image quality is a complicated process and as such will not be fully described by the single descriptors used for each of the parameters.

Comparisons between scanners are more reliable when comparing scans reconstructed with similar convolution filters. The uncertainty in quoted values of Q_2 is up to about ±15%, with a conservative estimate of ±10%.

Q_2 is calculated as follows:

$$Q_2 = \sqrt{\frac{f_{av}^3}{\sigma^2 z_1 CTDI_w}}$$

σ = image noise, expressed as a percentage for a 5cm^2 region of interest at the centre of the field of view in the standard ImPACT water phantoms.

f_{av} = spatial resolution, given as $(MTF_{50\%} + MTF_{10\%})/2$, where $MTF_{50\%}$ and $MTF_{10\%}$ are the spatial frequencies corresponding to the 50% and 10% modulation transfer function values respectively (in line pairs per cm). Reconstruction algorithms with standard spatial resolution values are chosen to minimise the dependency of Q_2 upon reconstruction algorithms. The reconstruction algorithm with $MTF_{50\%}$ and $MTF_{10\%}$ values as close as possible to 3.4 c/cm and 6.0 c/m is used.

z_1 = the full width at half maximum (FWHM) of the imaged slice profile (z-sensitivity). This is measured using the inclined plates method.

$CTDI_{vol}$ = volume weighted CT dose index.

Appendix 3: ImPACT and the MHRA

Background

One of the roles of the Medicines and Healthcare products Regulatory Agency (MHRA) is to fund evaluation programmes for medical devices and equipment. The programme includes evaluation of x-ray Computed Tomography Equipment currently available on the UK market.

MHRA aims to ensure that evaluation techniques keep abreast of improvements in CT imaging performance and that MHRA reports present evaluation information that is timely, useful and readily understood.

ImPACT

ImPACT (Imaging Performance Assessment of Computed Tomography) is the MHRA's CT evaluation facility. It is based at St George's Hospital, London, part of St George's Healthcare NHS Trust.

ImPACT has developed test objects and measurement procedures suitable for inter-comparing CT scanner performance. For each CT evaluation hundreds of images are obtained from the system under test and subsequently analysed using custom written software. Dose measurements are made using ionisation chambers, and x-ray film is used to obtain additional x-ray dose information.

MHRA support to purchasers and users

The ImPACT team is available to answer any queries with regard to the details of this report, and also to offer general technical and user advice on CT purchasing, acceptance testing and quality assurance.

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MHRA contact point for general information on the CT evaluation programme:

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Elephant and Castle
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email: `des@mhra.gsi.gov.uk`

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