ImPACT – Imaging Performance Assessment of CT Scanners

Four Slice CT Scanner Comparison Report

Version 6.01, March 2002

A report comparing the specification and imaging performance of the following CT scanners:

Manufacturer	Scanner model
GE	LightSpeed S Advantage
GE	LightSpeed Plus Advantage
Philips	Mx8000
Siemens	Somatom Sensation 4
Toshiba	Asteion Multi
Toshiba	Aquilion Multi

Compiled and prepared by members of the ImPACT group

www.impactscan.org

Table of contents

Introduction

Purpose of this report

In January 2000, the UK government announced the funding for the replacement, over a three-year period, of all non-helical CT scanners in use in England.

ImPACT has produced comparison reports for each phase of the purchase. The primary aim of these reports is to aid the equipment selection process by providing comparisons of CT scanners that are currently on the market.

The scope of this report is limited to CT scanners that are capable of acquiring four sets of attenuation data per tube rotation – 'quad' or 'four slice' scanners – rather than 'single slice' and 'dual' or 'twin slice' scanners, that can acquire one or two data sets per rotation.

The scanners included in the report are those that are currently on the market, and in particular, those that will generally be considered for purchase by NHS hospitals in the UK.

Comparison methods

The data given in this report are representative of the scanners as of January 2002, and are liable to change, as the performance of individual scanner models is changed and upgraded. In particular, optional features such as workstations and software packages may be listed as standard for the scanner replacement programme, but may not be included in other, separate scanner purchases.

There are two main areas for comparison of the scanners, specification and performance.

Specification comparison

The specification comparison is presented in two sections. The first is a side-by-side summary comparison of the specification of each scanner, workstation and related equipment, showing the parameters that are considered to be most important for inter-scanner comparison. An extended version of this, giving greater detail can be found in Appendix 1 – Extended Specification Comparison.

Scanner performance

This section presents the results of ImPACT's imaging and dose performance assessment of each of the scanners. Although manufacturers generally publish image and dose characteristics of their scanners, different measurement techniques and phantoms often make it very difficult to compare results from one scanner against another. The ImPACT performance assessments utilise standard techniques, and allow a fair, like-with-like comparison.

Scanners covered in this report

At the time of writing, there are five manufacturers of medical CT scanners; (in alphabetical order) GE Medical Systems, Philips Medical Systems, Shimadzu, Siemens AG and Toshiba Medical Systems. Of these, GE, Philips, Siemens and Toshiba currently produce four slice scanners. The scanner models in this report are listed in the table below.

Manufacturer	Scanner model
GE	LightSpeed S Advantage
GE	LightSpeed Plus Advantage
Philips	Mx8000
Siemens	Somatom Sensation 4
Toshiba	Asteion Multi
Toshiba	Aquilion Multi

The GE LightSpeed S Advantage and LightSpeed Plus Advantage models are grouped together in the specification section of this report, as the majority of their specifications are the same. Where there are exceptions to this, such as the LightSpeed Plus' faster scan speeds, these are indicated in the tables. The LightSpeed S Advantage is a replacement for the LightSpeed Advantage scanner. Unlike the latter, it uses the same gantry as the LightSpeed Plus. Performance data for the LightSpeed Advantage that was presented in previous versions of this report has been removed from this version. This is because the performance of the LightSpeed S Advantage is expected to follow that of the LightSpeed Plus Advantage.

GE recently introduced an eight slice version of the LightSpeed, called the LightSpeed Ultra Advantage. A separate Eight and Sixteen Slice CT Scanner report, MDA 02022, has been published that includes the specification for the LightSpeed Ultra Advantage.

Philips acquired Marconi Medical in October 2001. The Philips Mx8000 was formerly marketed as the Marconi Mx8000.

The Siemens Somatom Sensation 4 is an update to the previously available Somatom Volume Zoom. Siemens also market the Somatom Sensation 16, a sixteen slice development of the Sensation 4. Its specification is included in the Eight and Sixteen Slice Supplement report, MDA 02022.

The specifications of the Toshiba Asteion and Aquilion Multi scanners are listed separately as there is considerable of difference between the two. In particular, the current Asteion has a lower specification tube and generator, and a slower scan speed. In its current form it has poorer dosimetric performance than the Aquilion for equivalent image quality. Toshiba stated that they would upgrade the Asteion by the end of 2001 to give improved dosimetric performance. ImPACT has not yet had the opportunity to assess these modifications. There are also differences in reconstruction times, couch height, weight and size of room required.

Specification comparison

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Scanner gantry					
Generation	3rd	3rd	3rd	3rd	3rd
Aperture (cm)	70	70	70	72	72
Maximum scan field of view (cm)	50	50	51	50	50
Nominal slice widths for axial scans (mm)	0.625, 1.25, 2.5, 3.75, 5, 7.5, 10	0.5, 1, 2.5, 5, 8, 10, 16	0.5, 1, 1.5, 2.5, 5, 8, 10	0.5, 1, 2, 3, 4, 5, 8, 10	0.5, 1, 2, 3, 4, 5, 8, 10
Couch					
Length and width (cm)	239 x 62 (or 42 just for cradle)	243 x 67.5	243 x 40	200 x 47	200 x 47
Horizontal movement range (cm)	170	200	200	182	182
Vertical movement range out of gantry (cm)	51 - 99	48 - 100.8	48 - 102	30 - 87	30 - 95
Maximum weight on couch (kg)	180 (±0.25mm) 205 (±1mm)	200	200	205	205
Tube and generator					
Generator power rating (kW)	53.2	60	60	48	60
Anode heat capacity (MHU)	6.3	6.5	5.3 (run at 80% full loading)	4.0 (nominal) (claimed equiv. to 6.5)	7.5
Maximum anode cooling rate (kHU/min)	840	735	730	864	1,386
Guaranteed tube life	200,000 rotations	160,000 revolutions	160,000 seconds	200,000 rotations	200,000 rotations
Detection system					
Number of elements along z-axis	16	8	8	34	34
Effective length of each element at isocentre (mm)	16 x 1.25	2 x 1, 2 x 1.5, 2 x 2.5, 2 x 5	2 x 1, 2 x 1.5, 2 x 2.5, 2 x 5	4 x 0.5 30 x 1	4 x 0.5 30 x 1
Total effective length of detector array at isocentre (mm)	20	20	20	32	32
Future option for more slices/rotation	8 slices available	16 slices available. 32/64 slices WIP.	16 slices available last quarter 2002	8 slices - March 2002, 16 slices - March 2003	8 slices - March 2002, 16 slices - March 2003

Specification comparison

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
System start-up and calibration					
Total start-up time (in routine use)	2 mins 45 secs from fully off, 45 secs from standby	8-9 mins from fully off, 4-5 mins from standby	17 mins from fully off, 11 mins from standby	5 mins from fully off, 3 mins from standby	5 mins from fully off, 3 mins from standby
Total time from off to scanning in an emergency (mins)	< 3	8 - 9	17	2	2
Recommended frequency for performing full sets of detector calibrations	Once every 24 hours	1 per week	Not required	1 per week	1 per week
Scanning					
Scan times (s) * = Partial scans	0.8, 1, 2, 3, 4 [0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4]	0.3*, 0.5, 0.75, 1, 1.5, 2	0.36*, 0.54*, 0.5, 0.75, 1.0, 1.5	0.5*, 0.75, 1, 1.5, 2, 3	0.3*, 0.5, 0.75, 1, 1.5, 2, 3
Helical pitches (range and increment)	3 and 6	1 to 8 (0.1 steps)	1 to 8 (freely selectable)	2.5, 3, 3.5, 4.5, 5, 5.5, 6	2.5, 3, 3.5, 4.5, 5, 5.5, 6
Maximum continuous scan time (s)	120	100	100	100	100
Operator's console					
Number of monitors at console	2 (patient info and technique selection/ image display)	2 (patient set up and acquisition/ review, recon and filming)	2 (acquisition/ review and processing) (Shared database)	2 (acquisition/ review and processing)	2 (acquisition/ review and processing)
Control methods	Mouse, trackball, keyboard	Mouse, keyboard	Mouse, keyboard	Mouse, cursor, keyboard	Mouse, cursor, keyboard
Image storage					
Total hard disk storage capacity supplied as standard (Gbytes)	40.5	72	108	45	45
Archive options	MOD (standard)	MOD (standard)	MOD, CD writer (standard)	Rewritable MOD (standard)	Rewritable MOD (standard)

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
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	32 with IBO	40	60	50 prospective, 65 retro.	35 prospective, 50 retro.
(iii) helical abdomen scan	19	23	48	35 prospective, 50 retro.	25 prospective, 40 retro.
Simultaneous scanning and reconstruction	Yes	Yes	Yes	Yes	Yes
3D reconstruction					
3D reconstruction software	MIPs, SSD, 3D volume rendering, MPR, 3D virtual endoscopy	MIPs, SSD, 3D volume rendering, MPR, 3D virtual endoscopy	MIPs, SSD, 3D volume rendering, MPR, 3D virtual endoscopy	MIPs, SSD, 3D volume rendering, MPR, 3D virtual endoscopy	MIPs, SSD, 3D volume rendering, MPR, 3D virtual endoscopy
Additional facilities					
Independent workstation	Standard	Standard	Standard	Standard	Standard
Contrast injector	Optional	Optional	Optional	Optional	Optional
Contrast media bolus tracking	Standard	Standard	Standard	Standard	Standard
Real time CT (Level 1) and CT fluoroscopy (Level 2) software and hardware	Level 1 standard (level 2 opt. Q4 2001)	Optional (Continuous CT Imaging)	Optional (CARE Vision)	Level 1 standard, level 2 optional	Level 1 standard, level 2 optional
Hard-copy imaging device	Optional	Optional	Optional	Optional	Optional
Bone mineral densitometry	Optional	Optional	Optional	Optional	Optional
CT angiography	Standard	Standard	Standard	Standard	Standard
Dental	Optional	Optional	Optional	Optional	Optional
Radiotherapy CT simulation software	Optional	Optional	Available from 3rd party	Optional	Optional
Prospective ECG-triggered cardiac software	Optional	Optional	Optional	Optional	Optional
Retrospective ECG-gated cardiac software	Optional	Optional	Optional	Optional	Optional

Specification comparison

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Image transfer/connectivity					
DICOM service classes provided by CT console (SCP and SCU)	Storage SCU and SCP and Query/Retrieve (std.), Print (opt. LS, std. LS Plus), Modality worklist (opt.), Performed procedure step (opt, LS Plus)	Storage SCU and SCP, Query/ Retrieve, Print, Modality worklist	Storage SCU and SCP, Query/Retrieve, Print, Modality worklist	Storage SCU and Print (standard), Storage SCP and Modality worklist (optional)	Storage SCU and Print (standard), Storage SCP and Modality worklist (optional)
DICOM service classes provided by Independent workstation (SCP and SCU)	Storage SCU and SCP, Query/Retrieve and Print	Storage SCU and SCP, Query/Retrieve and Print	Storage SCU and SCP, Query/Retrieve and Print	Storage SCU and SCP, Print, Query/Retrieve	Storage SCU and SCP, Print, Query/Retrieve
Speed of scanner / workstation connections to local area networks (Mbits/s)	100	100	100	100	100

Introduction

In order to compare the performance of CT scanners, the ImPACT evaluation programme has developed a range of assessment techniques. These were described in detail in MDA98/25, *Type Testing of CT Scanners: Methods and Methodology for Assessing Imaging Performance and Dosimetry*. The results of this testing are presented in this section, which consists of four sets of data regarding different aspects of scanner performance.

The *dose efficiency* section looks at the overall image quality of the scanner relative to the radiation dose delivered to the patient, for both head and body scanning. This is presented in terms of the ImPACT Q value.

Spatial resolution compares the ability of the scanners to reproduce fine detail within an image, usually referred to as the high contrast spatial resolution. This is presented as the MTF_{50} and MTF_{10} values for inner ear and high contrast spine clinical studies, as well as the limiting clinical resolution of the scanner.

Geometric efficiency examines the *z*-axis dose utilisation of the scanners. This is expressed as the ratio of the imaged slice thickness to the x-ray beam thickness. In general, scanners with a high geometric efficiency will not produce large patient doses, particularly for narrow slice thicknesses, where geometric efficiencies are normally lowest.

Clinical scan tables lists the measured image quality and dose parameters for the standard ImPACT clinical scans.

Dose efficiency

Dose efficiency is a term used to describe the quality of a scanner's images relative to the radiation dose to the patient. It can be expressed in a number of ways, ImPACT normally use the 'Q-value', which combines measurements of noise, high contrast resolution, slice thickness and dose to produce an imaging figure of merit (see Appendix 2 for more details).

The Q_2 values presented in this section are for head and body imaging. 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:

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

Slice thickness: 4 x 5 mm for head, 2 x 10 mm for body.

Scan time: 1.5 or 2 s for head, 1s for body.

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 $CTDI_w$ of 50mGy for head and 15mGy for body scanning is listed. Z-sensitivity, image noise at 50 or 15 mGy and MTF values are also shown.

In the two tables below the scanners are ranked according to their Q_2 value.

Head scanning

Scanner	Recon Algorithm	mAs for 50mGy	z-sens (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	Q_2
GE LightSpeed	Stnd	278	4.9	0.37	3.5	6.6	6.3
Philips Mx8000	B	356	4.8	0.41	3.6	6.6	5.7
Siemens Volume Zoom	H40s	268	4.8	0.38	3.5	6.0	5.6
Toshiba Aquilion	FC27	241	4.8	0.41	3.4	6.6	5.5
Mean		286	4.8	0.39	3.5	6.5	5.8

Body scanning

Scanner	Recon Algorithm	mAs for 15mGy	z-sens (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	Q_2
GE LightSpeed Plus	Soft	182	9.8	1.2	3.6	6.0	2.2
Philips Mx8000	B	107	9.7	1.3	3.4	6.2	2.1
Siemens Volume Zoom	B30f	203	9.7	1.7	3.8	6.1	1.7
Toshiba Aquilion	FC11	130	9.6	1.5	3.2	5.9	1.7
Mean		155	9.7	1.4	3.5	6.1	2.0

Spatial resolution

The spatial resolution figures given below show the capabilities of the scanners to reproduce fine detail within an image.

Limiting resolution looks at the highest spatial resolution that can be achieved with the scanner, using a clinical reconstruction algorithm.

Limiting resolution

Scanner	Recon Filter	MTF_{50} (lp/cm)	MTF_{10} (lp/cm)
Siemens Volume Zoom	U90u	14.9	20.4
Philips Mx8000	E	8.9	17.8
Toshiba Aquilion	FC90	10.4	14.0
GE LightSpeed Plus	EDGE	9.5	13.6

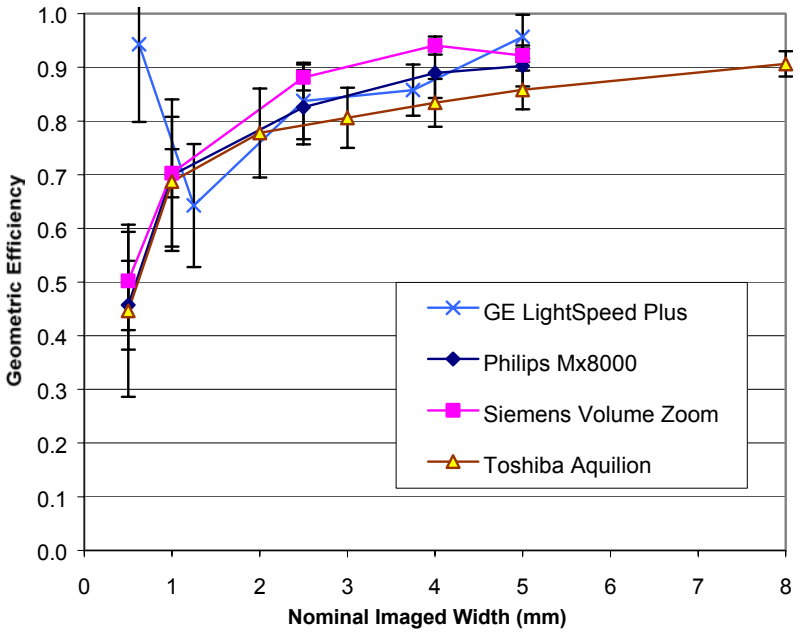
The scan parameters used for the limiting resolution table are those that produce the highest spatial resolution i.e. fine focal spot, long (>1 s) scan time, sharpest reconstruction algorithm, small reconstruction field of view. Scanners are ranked according to MTF_{10} value.

Geometric efficiency

Geometric efficiency is a measure of the scanners dose utilisation in the *z*-axis. This is expressed as the ratio of the axial imaged slice section thickness relative to the *z*-axis dose profile. For optimum imaging, the geometric efficiency should be 1, but it is often less, especially for narrow beam collimations where post-patient collimation may be necessary to bring the imaged slice thickness closer to the nominal value. Geometric efficiency values of greater than 1 can occur within the accuracy limits of the measurements.

The data is presented in the form of a table and a graph. The table gives geometric efficiency values for the setting closest to 4 x 1mm slice thickness and also for the slices narrower than 1 mm. Scanners are ranked according to geometric efficiency. The graph presents data for all slice widths, showing how geometric efficiency varies with nominal imaged slice width. The total *z*-sensitivity figure is the sum of individual imaged widths except for the Siemens Volume Zoom for 1 and 0.5 mm settings, and the Marconi Mx8000 and Toshiba Aquilion for 0.5 mm.

Scanner	Slice thickness (mm)	z-sensitivity (mm)	Dose profile (mm)	Total z-sensitivity (mm)	Geometric efficiency
Siemens Volume Zoom	4 x 1	1.0	5.5	3.8	0.70
Philips Mx8000	4 x 1	1.0	5.8	4.0	0.70
Toshiba Aquilion	4 x 1	1.2	6.7	4.6	0.69
GE LightSpeed Plus	4 x 1.25	1.1	7.1	4.5	0.64
GE LightSpeed Plus	2 x 0.625	0.9	1.9	1.8	0.94
Siemens Volume Zoom	2 x 0.5	0.6	2.5	1.2	0.50
Philips Mx8000	2 x 0.5	0.6	2.7	1.2	0.46
Toshiba Aquilion	4 x 0.5	0.6	5.0	2.2	0.45



Clinical scan tables

These are a sub-set of the standard ImPACT clinical scan tables for a range of examination types. It should be noted that the exposure parameters listed were those suggested by the manufacturer, but in practice they will vary from site to site. In particular, the settings for mA and scan time, which define patient dose, may vary widely from one centre to another.

Note that in these tables, the scanners are listed alphabetically by manufacturer.

Standard brain

Head scan reconstructed to show low contrast brain detail. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Conv. Filter	$CTDI_W$ (mGy)	z-sens. (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)
GE LightSpeed Plus	120	240	2	2 x 10	250	Soft	43	9.8	0.22	3.1	5.9
Philips Mx8000	120	250	0.75	4 x 5	250	UI-B*	35	4.8	0.37	2.9	5.8
Siemens Volume Zoom	120	380	1	2 x 10	250	H40s	71	9.7	0.22	3.5	6.0
Toshiba Aquilion	120	300	1	2 x 10	240	FC27	62	9.6	0.26	3.1	6.0
MEAN							53	8.5	0.27	3.2	5.9

*The UI-B filter on the Mx8000 has changed since the ImPACT assessment

Standard abdomen

Axial abdomen scan. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Conv. Filter	$CTDI_W$ (mGy)	z-sens. (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)
GE LightSpeed Plus	120	80	0.8	2 x10	380	Stnd	7	9.8	2.36	4.0	6.7
Philips Mx8000	120	250	0.5	4 x 5	380	B	18	4.8	1.67	3.4	6.2
Siemens Volume Zoom	120	150	0.5	2 x 10	380	B30f	11	9.7	1.96	3.8	6.1
Toshiba Aquilion	120	150	0.5	2 x 10	380	FC10	17	9.6	1.97	3.6	6.7
MEAN							13	8.5	2.0	3.7	6.4

Helical abdomen

Helical abdomen scan. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	Pitch	Conv. Filter	$CTDI_W$ (mGy)	z-sens. (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)
GE LightSpeed Plus*	120	160	0.5	5	6	Stnd	10	6.4	2.48	3.8	6.5
Philips Mx8000	120	250	0.75	6.5	5	B	14	6.7	1.67	3.5	6.5
Siemens Volume Zoom	120	206	0.5	5	5	B30f	13	5.2	2.12	3.7	6.1
Toshiba Aquilion	120	150	0.5	7	3	FC10	22	7.9	1.44	3.4	6.1
MEAN							17	6.6	1.7	3.5	6.2

* The LightSpeed S Advantage would use 0.8 s scan time, as it does not have a 0.5 s scan setting

Inner ear

High contrast inner ear exam, using a narrow slice for good resolution in the *z*-axis. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Conv. Filter	$CTDI_W$ (mGy)	z-sens. (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	MTF_{10} as mm
GE LightSpeed Plus	140	120	0.8	2x 0.63	120	Bone+	45	0.9	6.6	9.4	11.7	0.43
Philips Mx8000	120	330	2	4 x 1	120	U.H./E	62	1.0	4.0	8.8	17.7	0.28
Siemens Volume Zoom	140	100	1	4 x 1	120	U90u	34	1.2	19.9	14.9	20.4	0.25
Toshiba Aquilion	120	150	0.5	4 x 0.5	120	FC81	73	0.5	18.0	10.2	12.1	0.41
MEAN							56	0.9	13.9	11.3	16.7	0.31

High resolution spine

High contrast spine examination. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Conv. Filter	$CTDI_W$ (mGy)	z-sens. (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	MTF_{10} as mm
GE LightSpeed Plus	120	320	2	2x2.5	120	Bone+	38	2.4	13.3	9.7	11.8	0.42
Philips Mx8000	140	350	1.5	4 x 2.5	180	D	41	2.4	8.7	6.9	12.2	0.41
Siemens Volume Zoom	140	360	1	4 x 2.5	120	B60s	42	2.3	10.8	7.6	10.0	0.50
Toshiba Aquilion	120	300	1.5	4 x 2	120	FC30	38	1.9	10.5	7.9	11.4	0.44
MEAN							40	2.2	10.0	7.4	11.2	0.45

Appendix 1: Extended specification comparison

Scanner gantry

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Generation	3rd	3rd	3rd	3rd	3rd
Slipring	Low voltage	Low voltage	Low voltage	Low voltage	Low voltage
Aperture (cm)	70	70	70	72	72
Scan fields of view (cm)	25 and 50	25 and 50	50	18, 24, 32, 40, 50	18, 24, 32, 40, 50
Nominal slice widths for axial scans (mm)	0.625, 1.25, 2.5, 3.75, 5, 7.5, 10	0.5, 1, 2.5, 5, 8, 10, 16	0.5, 1, 1.5, 2.5, 5, 8, 10	0.5, 1, 2, 3, 4, 5, 8, 10	0.5, 1, 2, 3, 4, 5, 8, 10
Tilt range (degrees)	± 30	± 30	± 30	± 30	± 30
Type of positioning lights	Laser	Laser	Laser	Laser	Laser

Patient couch

Couch top	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Material	Carbon fibre	Carbon fibre	Laminated wood + carbon fibre	Carbon fibre	Carbon fibre
Length and width (cm)	239 x 62 (or 42 just for cradle)	243 x 67.5	243 x 40	200 x 47	200 x 47
Horizontal movement					
Horizontal movement range (cm)	170	200	200	182	182
Horizontal movement speeds (mm/sec)	up to 100	0.5 - 100	1 - 150	10 or 100	10 or 100
Accuracy/reproducibility of table positioning (mm)	± 0.25	± 0.25	± 0.5	± 0.25	± 0.25
Scannable horizontal range (cm):					
(i) without table top extension	170	165	157	144	144
(ii) with table top extension(s)	170	187	165	155	155
Vertical movement					
Vertical movement range out of gantry (cm)	51 - 99	48 - 100.8	48 - 102	30 - 87	30 - 95
Vertical movement range in gantry (cm)	88 - 99	86 - 100.8	86 -102	73 - 87	73 - 95
Minimum couch top height outside gantry (cm)	51	48	48	30	30
Weight bearing properties					
Maximum weight allowed on couch (kg)	205	200	200	500	500
Maximum weight on couch which still achieves stated performance specifications (kg)	180 (±0.25mm) 205 (±1mm)	200	200	205	205

X-ray generator

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Type	High frequency	High frequency	High frequency	High frequency	High frequency
Location	Rotation assembly	Rotation assembly	Rotation assembly	Rotation assembly	Rotation assembly
Power rating (kW)	53.2	60	60	48	60
kV settings available	80, 100, 120, 140	90, 120, 140	80, 120, 140	80, 100, 120, 135	80, 100, 120, 135
mA range and step size	10 - 440 (10mA steps)	28 - 500 (1mA steps)	28 - 500 (10mA steps)	10 - 400 (10mA steps)	10 - 500 (10mA steps)
Max. mA allowed for each kV	80kV: 400mA 100kV: 420mA 120kV: 440mA 140kV: 380mA	90kV: 500mA 120kV: 500mA 140kV: 425mA	120kV: 500mA 140kV: 428mA	80 -120 kV: 400mA 135kV: 350mA	80 -120 kV: 500mA 135kV: 440mA

X-Ray Tube

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Type and make	GE Performix	Marconi DFS	Siemens Dura Akron-B	Toshiba Helicool	Toshiba Megacool
Focal spot size(s) (mm), quoted to IEC 336/93 standard	0.6 x 0.7 0.9 x 0.9	0.5 x 0.7 0.8 x 1.2	0.5 x 0.7 0.8 x 1.2	0.9 x 1.3 1.7 x 1.6	0.9 x 0.8 1.6 x 1.4
Total filtration (inherent + beam shaping filter) at central axis (mm Al equivalent)	4.75 (70kV, head) 5.65 (70kV, body)	> 5.5	2 + 0.6mmTi (head), 1.2mmTi (body)	> 1 (inh) + 1.5	> 1 (inh) + 1.5
Anode heat capacity (MHU)	6.3	6.5	5.3 (run at 80% full loading)	4.0 (nominal) (claimed equiv. to 6.5)	7.5
Maximum anode cooling rate (kHU/min)	840	735	730	864	1,386
Method of cooling	Oil to air	Pumped oil/forced air	Oil to air	Oil/forced air with liquid metal bearings	Oil/forced air
Guaranteed tube life	200,000 rotations	160,000 revolutions	160,000 seconds	200,000 rotations	200,000 rotations

Detection system

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Detector type	Solid state (HiLight / Lumex)	Solid state (High speed ceramic)	Solid state (Ultra Fast Ceramic)	Solid state	Solid state
Number of detectors per row	880 (plus 32 reference elements)	672 (plus 2 reference elements)	672 (plus ref detectors)	896 (plus 1 pair ref detectors)	896 (plus 1 pair ref detectors)
Number of elements along z-axis	16	8	8	34	34
Effective length of each element at isocentre (mm)	16 x 1.25	2 x 1, 2 x 1.5, 2 x 2.5, 2 x 5	2 x 1, 2 x 1.5, 2 x 2.5, 2 x 5	4 x 0.5 30 x 1	4 x 0.5 30 x 1
Total effective length of detector array at isocentre (mm)	20	20	20	32	32
Future option for more slices/rotation	8 slices available	16 slices available, 32/64 slices WIP	16 slices available last quarter 2002	8 slices - March 2002, 16 slices - March 2003	8 slices - March 2002, 16 slices - March 2003

System start-up and detector calibration

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Power-on to warm-up time (mins)	2 from fully off, 0 from standby	6 from fully off, approx. 2 from standby	12 from fully off, 6 from standby	2 from fully off, 0 from standby	2 from fully off, 0 from standby
Tube warm-up time from 'cold' to operating temperature (mins)	45 secs	2 - 3	3	2 (0 in an emergency)	2 (0 in an emergency)
Time to perform detector calibrations at warm-up (mins)	Included in 45s tube warm-up	3	2	1	1
Recommended frequency for any additional calibration by the radiographer	Once every 24 hours	1 per week	Not required	1 per week	1 per week
Time to perform these additional calibrations (mins)	20 (inc warm-up)	2	Not required	Up to 20	Up to 20
Total time from fully off to scanning in an emergency (mins)	< 3	8 - 9	17	2	2

Scan parameters

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Reconstruction fields of view (cm)	9.6 - 50	2.5 - 50 (0.1 steps)	5 - 50	0 - 50	0 - 50
Number of simultaneous slices at each nominal axial slice width (mm)	2 x 0.625, 4 x 1.25, 4 x 2.5, 4 x 3.75, 4 x 5, 2 x 7.5, 2 x 10	2 x 0.5, 4 x 1, 4 x 2.5, 4 x 5, 2 x 8, 2 x 10	2 x 0.5, 4 x 1, 4 x 2.5, 4 x 5, 2 x 8, 2 x 10	4 x 0.5, 4 x 1, 4 x 2, 4 x 3, 4 x 4, 4 x 5, 4 x 8, 2 x 10	4 x 0.5, 4 x 1, 4 x 2, 4 x 3, 4 x 4, 4 x 5, 4 x 8, 2 x 10
Scan times for axial scans (s) * = Partial scans	0.8, 1, 2, 3, 4 [0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4]	0.3*, 0.5, 0.75, 1, 1.5, 2	0.36*, 0.54*, 0.5, 0.75, 1.0, 1.5	0.5*, 0.75, 1, 1.5, 2, 3	0.3*, 0.5, 0.75, 1, 1.5, 2, 3
kV settings available	80, 100, 120, 140	90, 120, 140	80, 120, 140	80, 100, 120, 135	80, 100, 120, 135
mA range and step size	10 - 440 (10mA steps)	28 - 500 (1mA steps)	28 - 500 (10mA steps)	10 - 400 (10mA steps)	10 - 500 (10mA steps)
Max. mA allowed for each kV	80kV: 400mA 100kV: 420mA 120kV: 440mA 140kV: 380mA	90kV: 500mA 120kV: 500mA 140kV: 425mA	120kV: 500mA 140kV: 428mA	80 -120 kV: 400mA 135kV: 350mA	80 -120 kV: 500mA 135kV: 440mA

Helical scanning

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Rotation times for helical scanning (s)	0.8, 1 [0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 4]	0.5, 0.75, 1, 1.5	0.5, 0.75, 1, 1.5	0.75, 1, 1.5	0.5, 0.75, 1, 1.5
Pitches available for routine scanning (range and increment)	3 and 6	1 to 8 (0.1 steps)	1 to 8 (freely selectable)	2.5, 3, 3.5, 4.5, 5, 5.5, 6	2.5, 3, 3.5, 4.5, 5, 5.5, 6
Recommended pitches for optimal image quality	3 and 6	1, 1.5, 2, 2.5, 3.5, 5, 8	4 to 8	2.5, 3, 3.5, 4.5, 5, 5.5, 6	2.5, 3, 3.5, 4.5, 5, 5.5, 6
Helical interpolation algorithms available	180º LI, 360° & z-filter interpolation	180º, 360º, High order non linear filters	Adaptive Axial Interpolator	180º, 360º, Muscot	180º, 360º, Muscot
Maximum number of rotations in one helical run at standard abdomen parameters	70 (300mA) 90 (270mA) 110 (250mA)	200	200 (300mA, .5s) 133 (200mA, .75s) 100 (150mA, 1s) 66 (100mA, 1.5s)	115 (190mA, .75s) 133 (160mA, .75s)	120 (300mA, .5s) 200 (180mA, .5s)
Maximum continuous scan time (s)	120	100	100	100	100
Gantry tilt range for helical scanning (degrees)	± 30	Info. not available	± 30	W.I.P.	W.I.P.

Scan projection radiograph (SPR)

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Maximum SPR length (mm)	1600	1024	1024	1390	1390
SPR field dimensions (mm x mm)	500 x 1600	width: 500 length: 100 - 1024 (1mm steps)	512 x 1024	width: 240, 400, 500, length: 200 - 1,390	width: 240, 400, 500, length: 200 - 1,390
Angular positions of X-ray tube available for SPR (degrees)	any angle from 0 - 355 (5° steps)	0, 90, 180, 270	AP, PA, LAT (oblique in 10º steps)	0, 90, 180, 270 (oblique in 5º steps)	0, 90, 180, 270 (oblique in 5º steps)
Real time image	Yes	Available next s.w. release (Recon. time curently 2s)	Yes	Yes	Yes
Accuracy of slice prescription from the scanogram (mm)	± 0.25	< ± 1	± 0.5	± 0.25	± 0.25
Accuracy of distance measurements from SPR's taken at isocentre (lateral and axial directions) (mm)	< 2 x image pixel size	± 0.25	± 0.5	< ± 0.5 mm	< ± 0.5 mm

■ Manufacturer's performance data

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
High contrast spatial resolution					
Resolution (lp/cm) for sharpest clinical algorithm	0% MTF: 15.4 lp/cm (Edge alg, small focus)	1% MTF: 24 lp/cm	2% MTF: 24 lp/cm (0.75 s scan)	2% MTF : 14.5 lp/cm (200mA, 1s, small focus)	2% MTF : 14.5 lp/cm (200mA, 1s, small focus)
Low contrast resolution					
Smallest rod size (mm) discernable at given parameters in 20 cm CATPHAN	5mm @ 0.3% @ 18mGy: 120kV, 140mAs, 0.5 - 2.0s, 10mm, 2i, 25cmDFOV, Std alg.	4mm @ 0.3% @ 27 mGy	5mm @ 0.3% @ 21mGy: 120kV, 150 mAs - std body, 100mAs - special head mode, 1 x 10mm	5mm @ 0.3%: 120kV, 150mAs, 10mm, FC41	5mm @ 0.3%: 120kV, 150mAs, 10mm, FC41
Dose					
CTDI (mGy/100 mAs) for axial standard brain scans at given parameters:	120 kV, 260 mAs, 10 mm	120 kV	120kV, 400mA, 0.75s, 20 mm	120kV, 300mA, 1s, 20 mm	120kV, 300mA, 1s, 20 mm
- centre of CTDI phantom	18.2	13.6	18.3	21.2	17.6
- periphery of CTDI phantom	18.5	14.9	22.2	25.1	20
CTDI (mGy/100mAs) for axial standard abdomen scans	120 kV, 260 mAs, 10 mm	120 kV	120 kV, 440 mA, 0.5s, 20 mm	120 kV, 200mA, 0.75s, 20 mm	120 kV, 200mA, 0.75s, 20 mm
- centre of CTDI phantom	5.5	4.2	4.6	6.2	5.9
- periphery of CTDI phantom	11.4	8.3	10.6	13.7	13.1
Dose profile FWHM (mm) (focal spot size in brackets)	20: 20.8(l) 15: 17.2 (s) 10: 11.5 (s) 5: 7.1 (s) 1.25: 3.5 (s) 2x0.63:1.9 (s)	Info. not available	20: 21.3 (l) 16:16.4 (l) 10: 11.15 (l) 4: 5.5 (l) 1:2.2 (l)	32: 35.5 (l) 20: 22.8 (l) 16: 18.7 (l) 12: 15.4 (s) 8: 10.7 (s) 4: 7.1 (s) 2: 5.2 (s)	32: 35.9 (l) 20: 23.2 (l) 16: 19.0 (l) 12: 15.6 (s) 8: 10.9 (s) 4: 7.2 (s) 2: 5.3 (s)

Factors affecting image quality

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Dose					
Post-patient collimation for narrow slices	No	Yes	Yes	No	No
Automatic mA adjustment according to body dimensions or density during examination	Yes	N/A	Yes - CARE Dose	Yes	Yes
Noise					
Adaptive filtration for noise reduction	Low signal correction	Adaptive image enhancement or smoothing for three density ranges	Yes (automatic)	Yes (user programmable)	Yes (user programmable)
Resolution					
Quarter detector shift	Yes	Yes	Yes	Yes	Yes
Moving (dynamic/flying) focal spot	No	Yes	Yes	No	No
Number of imaging detectors per row	880	672	672	896	896
Sampling frequency	1408 Hz	2,320 views (in standard 0.75s imaging mode)	1160 views/rot (0.5s scan), 2320 views/rot (> 0.5s scans)	1200 views/sec	1800 views/sec (0.5s scan), 1200 views/sec (>0.5s)
Artefacts					
Artefact reduction algorithms	Iterative Bone Option (IBO), Motion correction	Iterative bone correction	Modified beam hardening (abdomen, pelvis, shoulder), Motion correction (sequential modes)	Beam hardening correction, Raster Art. Suppression Protocol (RASP), Stack scanning, Automatic patient motion correction	Beam hardening correction, Raster Art. Suppression Protocol (RASP), Stack scanning, Automatic patient motion correction
Cone beam correction	Info. not available	Info. not available	No correction	MUSCOT	MUSCOT

■ Operator's console

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Image monitor					
Diagonal dimension of image screen (inches)	20	20	18.1	21	21
Number of monitors at console (functions of each if > 1)	2 (patient info and technique selection/ image display)	2 (patient set up and acquisition/ review, recon and filming)	2 (acquisition/ review and processing) (Shared database)	2 (acquisition/ review and processing)	2 (acquisition/ review and processing)
Image display					
Image area matrix dimensions	512 x 512, 768 x 768, 1024 x 1024	340, 512, 768, 1024	1024 x 1024	512 x 512, 512 x 1024, 1024 x 1024	512 x 512, 512 x 1024, 1024 x 1024
Usual range of CT number displayed (HU)	-1024 to +3071	-1000 to +3094	-1024 to +3071 (-10,240 to +30,710 if metal implants)	-1024 to +8191	-1024 to +8191
Dose information					
Weighted CTDI ($CTDI_W$) diplayed on console	Yes	Yes	Yes	Yes	Yes
Dose Length Product (DLP) displayed on console	Yes	Info. not available	Yes	Yes	Yes
Geometric efficiency displayed on console when <70%	Yes	No	Yes	Yes	Yes
Hardware interface					
Control methods	Mouse, trackball, keyboard	Mouse, keyboard	Mouse, keyboard	Mouse, cursor, keyboard	Mouse, cursor, keyboard

Main computer

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Make and model	Silicon Graphics Octane	2 x Silicon Graphics O_2	2 x Siemens PC compatible, with array processors (Vol. Wizard and Vol. Navigator)	2 x Silicon Graphics O_2	2 x Silicon Graphics O_2
Operating system	IRIX 6.5	Unix	Windows NT	IRIX	IRIX
Type and speed of CPU	MIPS R12000 CPU 300 MHz	2 x RISC processor 300 MHz (one for each console)	Wiz: 2xCPU Nav: 1xCPU Each Primergy CISC CPU is 850 MHz	R5000 (scan console) + R12000 (display console) 300 MHz	R5000 (scan console) + R12000 (display console) 300 MHz
Amount of computer RAM (Mbytes):					
(i) supplied as standard	512	2 x 1024	Wiz: 1536 Nav: 1024	2 x 1024	2 x 1024
(ii) maximum	1.5GB with Direct 3D option	2 x 1024	Wiz: 1536 Nav: 1024	2 x 1024	2 x 1024

Image Storage

Hard disk storage	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Total standard hard disk capacity (Gbytes)	40.5	72	108	45	45
Maximum hard disk capacity (Gbytes)	40.5	72	108	90	90
Hard disk capacity for image storage (Gbytes and no. of uncompressed 512x512 images)	18 (20,000 images)	72 (54,000 images)	36 (60,000 images)	16,000 images	16,000 images
Hard disk capacity for storage of raw data files (Gbytes and no. of data files)	18 (2000 data files)	72 (approx. 1800 data files)	72 (70,000 data files)	4,000 rotations	4,000 rotations
Archive options					
Archive options	MOD (standard)	MOD (standard)	MOD, CD writer (standard)	Rewritable MOD (standard)	Rewritable MOD (standard)
Capacity of a single archive disk (Gbytes and no. of images)	2.3 (9400 losslessly compressed 512 x 512 images or 700 raw data files)	4.1 (15,650 512 x 512 images. Factor 2-3 compression)	MOD: 4.1 (26,000 losslessly compressed images) CD-R: 0.65 (4800 compressed images) 256 x 256 matrix	2.6 (9600 512 x 512 images - slightly compressed)	2.6 (9600 512 x 512 images - slightly compressed)
Time to mount an archive disk or tape (s)	5-6 in background operation	Immediate (disk continually accessible)	Approx. 30 for full disk	20 for full disk	20 for full disk
Archive data transfer rate (images/s)	0.5	> 3	2 - 3	Approx. 1	Approx. 1

Image reconstruction

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Reconstruction matrix	512 x 512	340, 512, 768, 1024	256 x 256, 512 x 512	256 x 256, 512 x 512	256 x 256, 512 x 512
Minimum reconstruction interval in helical scanning (mm)	0.1	0.1	0.1	0.1	0.1
Reconstruction times					
Time (s) from the start of data acquisition to the appearance of the 30th image of a series:					
(i) standard axial brain scan	32 with IBO	40	60	50 prospective, 65 retro.	35 prospective, 50 retro.
(ii) axial spine scan	20	40	60	45 prospective, 60 retro.	30 prospective, 45 retro.
(iii) helical abdomen scan	19	23	48	35 prospective, 50 retro.	25 prospective, 40 retro.
Parallel processing details					
Simultaneous scanning and reconstruction	Yes	Yes	Yes	Yes	Yes
Any delay in either scanning or reconstruction when performed concurrently	No	No	No	No	No
Simultaneous scanning and routine analysis	Yes	Yes	Yes	Yes	Yes
Simultaneous scanning and archiving and/or hard copying	Yes	Yes	Yes	Yes	Yes
Simultaneous scanning and transfer to second console/workstation	Yes	Yes	Yes	Yes	Yes

3D reconstruction

3D reconstruction on main console (MC) and workstation (WS)	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
MIPs and MinIPs (maximum and minimum intensity projections)	MC-standard, WS-standard (MIP & MinIP)	MC-standard, WS-standard (Angio MIP)	MC-standard, WS-standard	MC-standard, WS-standard	MC-standard, WS-standard
SSD (3D Shaded Surface Display)	MC-optional, WS-standard (3D)	MC-standard, WS-standard (3D SSD)	MC-standard, WS-Standard	MC-standard, WS-standard	MC-standard, WS-standard
3D volume rendering software	MC-N/A, WS-standard (Volume Rendering)	MC-standard, WS-standard (Vol Rend 4D Angio)	MC-Option, WS-standard	MC-standard, WS-standard	MC-standard, WS-standard
3D virtual endoscopy	MC-optional, WS-standard (Navigator)	MC-standard, WS-standard (V-endo Voyager)	MC-WIP, WS-standard	MC-optional, WS-standard	MC-optional, WS-standard
MPR (Multi-planar reconstruction)	MC-standard, WS-standard (MPR & MPVR)	MC-standard, WS-standard (MPR)	MC-standard, WS-standard	MC-standard, WS-standard	MC-standard, WS-standard
Planes available in MPR	Axial, para-axial, sagittal, coronal, oblique, curvilinear	All planes, any oblique (identical on console and workstations)	Axial, sagittal, coronal, oblique, curvilinear	Axial, sagittal, coronal, oblique, curved with cross cut through the curved reformat	Axial, sagittal, coronal, oblique, curved with cross cut through the curved reformat

Optional features

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Contrast injector	Optional	Optional	Optional	Optional	Optional
Contrast media bolus tracking	Standard (SmartPrep)	Standard (BolusPro Ultra)	Standard (CARE Bolus)	Standard	Standard
CT fluoroscopy software and hardware	Level 1 standard (level 2 opt. Q4 2001)	Optional (Continuous CT Imaging)	Optional (CARE Vision)	Level 1 standard, level 2 optional	Level 1 standard, level 2 optional
Hard-copy imaging device	Optional	Optional	Optional	Optional	Optional
Radiotherapy planning accessories					
Radiotherapy planning table top	Optional (RT flat pad and 'Exact' couch top)	Optional (RTP)	Optional	Optional	Optional
Carbon fibre breast board	optional	N/A	N/A	N/A	N/A
Means for attaching patient immobilisation devices and a stereotactic frame to the end of the couch	Optional (Exact couch E8505MA)	Optional (Stereotaxis)	Optional	Optional	Optional
Software Packages on main console (MC) and workstation (WS)					
Bone mineral densitometry	MC-N/A, WS-optional (BMD)	MC-optional, WS-optional (Q BMAP II)	MC-optional, (Osteo CT) WS-N/A	MC-optional, WS-N/A	MC-optional, WS-N/A
CT angiography	MC-standard, WS-standard (inc. MIP MinIP Average)	MC-standard, WS-standard (Angio MIP)	MC-standard, WS-standard	MC-standard, WS-standard	MC-standard, WS-standard
Dental	MC-optional, WS-optional (Dentascan)	MC-optional, WS-optional (DENT -3)	MC-optional, (Dental CT) WS-N/A	MC-optional, WS-optional	MC-optional, WS-optional
Radiotherapy CT simulation software	MC-N/A, WS-optional (CT sim)	MC-optional, WS-optional (ACQSim)	Available from 3rd party	MC-optional, WS-N/A	MC-optional, WS-optional
Prospective ECG-triggered cardiac software	MC-optional, WS-optional (SmartScore)	MC-optional, (Prospective Gating) WS-N/A	MC-optional (Heart View), WS-N/A	MC-optional, WS-N/A	MC-optional, WS-N/A
Retrospective ECG-gated cardiac software	WS-optional CardIQ coronary artery imaging, MC-N/A	MC-optional (Retrospective Tagging), WS-N/A	MC-optional (Heart View), WS-N/A	MC-optional, WS-N/A	MC-optional, WS-N/A

Installation requirements

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Environmental requirements (max/min temperature, humidity) in scanner room	20-28 ºC, 30-60% non-cond. rel. humidity	15-30° C, rel. humidity 40-60%	15-28 ºC, rel. air humidity 15-75%	18-28 ºC, humidity 40-80%	18-28 ºC, humidity 40-80%
Environmental requirements (max/min temperature, humidity) in scanner control room	20-28 ºC, 30-60% non-cond. rel. humidity	15-30° C, rel. humidity 40-60%	15-28 ºC, rel. air humidity 15-75%	18-28 ºC, humidity 40-80%	18-28 ºC, humidity 40-80%
Peak heat output from system during scanning (kW)	7.1 (75 rot/patient, 4 patient/hour)	13.5	13.5	10.6 max	11.7 max
System cooling method	Output to air	Water/water or water/air	Water/water	Output to air	Output to air
Air conditioning requirements for scanner room of minimum floor area	Recom-mended	Not required, other than for patient comfort	None	Not necessary but recommended	Not necessary but recommended
Minimum floor area required for the system (m^2)	28	25	25	20	25 (36 recommended)
Dimensions of:					
(i) Gantry (H x W x D (mm)) and weight (kg)	1887 x 2230 x 1007 1350kg	2050 x 2290 x 980 2100kg	1990 x 2220 x 890 2100kg	1760 x 1970 x 870 1300kg	1950 x 2320 x 960 1750kg
(ii) Couch (H x W x L (mm)) and weight (kg)	1120 x 610 x 2387 335kg	480 x 670 x 2550 500kg	850 x 680 x 2430 500kg	390 x 620 x 2390 330kg	390 x 620 x 2390 330kg
(iii) Supplementary units (H(mm)xW(mm)xD(mm)) and weight (kg)	Power Unit: 1270 x 762 x 585, 363kg	Power Unit: 1800 x 900 x 750, 550kg Cooling Unit: 1800 x 900 x 750, 500kg	Power Unit: 1815 x 905 x 800, 550kg Cooling Unit: 1815 x 905 x 860, 200kg	Transformer: 980 x 800 x 770, 550kg	Transformer: 980 x 800 x 770, 550kg
Power supply requirements	3 phase 380-480V, 90kVA	3 phase 380-480V, 90kVA	3 phase 380-480V, 66-83kVA	3 phase 380-440V, 75kVA	3 phase 380-440V, 100kVA

Independent workstation

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Is a workstation provided?	Standard	Standard: MX VIEW	Standard: LEONARDO	Standard: AlatoView	Standard: AlatoView
Computer make and model	Sun ultraSPARC 60	Silicon Graphics O_2	Siemens Fujitsu Pentium 4	Silicon Graphics O_2	Silicon Graphics O_2
Operating system	Solaris 2.7	Unix	Windows NT	Unix	Unix
Type and speed of CPU	Two 450 MHz ultraSPARC II	RISC processor 300 MHz	2 x Pentium (at least 850 MHz)	R12000, 300 MHz	R12000, 300 MHz
Amount of computer RAM (Mbytes):					
(i) supplied as standard	1024	1024	1024	1024	1024
(ii) maximum	2048	1024	1024	1024	1024
Total hard disk storage capacity (Gbytes):					
(i) supplied as standard	36	18	Minimum 36	27	27
(ii) maximum	54	18	Currently 36	27	27
Archive options	CD-R (standard), MOD (optional)	MOD (Standard)	CD Rom (Standard), MOD (optional)	MOD (optional)	MOD (optional)
Capacity of a single archive disk (Gbytes)	CD-R: 640MB MOD: 2.3GB	4.1 (15,650 512 x 512 images. Factor 2-3 compression)	MOD: 4.1 (26,000 losslessly comp. images) CD-R: 0.65 (4800 comp. images) 256 x 256 matrix	2.6 (9600 512 x 512 images - slightly compressed)	2.6 (9600 512 x 512 images - slightly compressed)
Environmental requirements (max/min temperature, humidity) for workstation	10-40 ºC, 20-80 % rel. non-cond. humidity at 40 ºC	0-40 °C	15-30 ºC 20-85% rel. humidity	18-28 ºC, humidity 40-80%	18-28 ºC, humidity 40-80%

Image transfer and connectivity

	GE LightSpeed S [LS Plus]	Philips Mx8000 Quad	Siemens Sensation 4	Toshiba Asteion Multi	Toshiba Aquilion Multi
Speed of scanner/workstation connections to local area networks (Mbits/s)	100	100	100	100	100
Remote PC access to images on workstation	Optional	JPACS or Radworks (optional). Radworks provides full image distribution	Optional	Optional	Optional
DICOM service classes provided by CT console (SCP and SCU)	Storage SCU and SCP and Query/Retrieve (std.), Print (opt. LS, std. LS Plus), Modality worklist (opt.), Performed procedure step (opt, LS Plus)	Storage SCU and SCP, Query/ Retrieve, Print, Modality worklist	Storage SCU and SCP, Query/Retrieve, Print, Modality worklist	Storage SCU and Print (standard), Storage SCP and Modality worklist (optional)	Storage SCU and Print (standard), Storage SCP and Modality worklist (optional)
DICOM service classes provided by independent workstation (SCP and SCU)	Storage SCU and SCP, Query/Retrieve and Print	Storage SCU and SCP, Query/Retrieve and Print	Storage SCU and SCP, Query/Retrieve and Print	Storage SCU and SCP, Print, Query/Retrieve	Storage SCU and SCP, Print, Query/Retrieve

Appendix 2: Image quality assessment and Q

Statistical noise, spatial resolution and slice sensitivity are fundamental parameters describing the amount of object information retrievable from an image, or its image quality. X-ray 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. The Q-value incorporates dose, noise, spatial resolution and slice width into one number. This figure is derived from a relationship between image quality and dose received.

A dose efficiency factor has a fundamental meaning, in that a dose efficient scanner will produce good resolution at minimum dose and noise. However, it can take a number of forms depending on how the various parameters are measured and quoted.

The Q-value used in this comparison report, Q_2, is the same one used in Comparison Report 12 (MDA/00/11), which was modified from the previous value used by ImPACT, Q_1.

Q_2 is defined as follows:

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

where:

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).

z_1 = the full width at half maximum (FWHM) of the imaged slice profile (z-sensitivity). This is measured using the inclined plates method for axial imaging, and using a 0.1mm thickness, 6mm diameter tungsten disc for helical scanning

$CTDI_w$ = weighted CT dose index, as defined in EUR 16262

The Q-factor is in part empirical and it should be used with caution. It is not an absolute figure, as its derivation relies on assumptions of the shape of convolution filter used. Comparisons between scanners will be more reliable when comparing scans reconstructed with similar convolution filters. It is of most importance when considering the standard scans for head or body. The uncertainty in this value is up to about +/-15%, with a conservative estimate of ±10%.

Appendix 3: Manufacturers' comments

Responses are included from the following manufacturers :

GE Medical Systems

Philips Medical Systems

Siemens Medical Solutions

Toshiba Medical Systems

Where appropriate ImPACT have included a short reply.

Response from GE Medical Systems

2nd May 2001

ImPACT 4-Slice CT Comparison Reports

Dear Sue

Thank you, for the draft version of the report.

We were, of course pleased with the results of the comparisons, as these showed both the Lightspeed and the Lightspeed Plus to have the best overall image quality with due regard to dose.

I would like to state that all of the protocols which we suggested for the clinical scan tables, are protocols which we recommend as being suitable for clinical purposes. Therefore, these show the quality, which can be achieved, in a clinical setting.

One final comment

Where values in the tables, are very close, it would be useful to have an indication of the degree of error in the measurements, to see whether the small differences are significant. Would this be possible in future reports?

Kind regards

Yours sincerely

Paul Morgan

CT Clinical Scientist

Response from Philips Medical Systems

The following response was received in relation to the Marconi Mx8000 scanner before Philips' purchase of Marconi Medical Systems in October 2001.

Dear Sue,

Thank you and all the ImPACT team for all your work on producing a thorough Blue Cover Report for the CT scanner comparison and assessment.

On behalf of Marconi Medical Systems we have no additional comments to make and look forward to receiving a hardback copy and working with you all in the future.

Best Regards

Derek Tarrant

CT Product Manager

Marconi Medical Systems UK

28/05/01

Response from Siemens Medical Solutions

10/05/01

ImPACT Comparison Reports; Manufacturer's Response

Dear Sue,

Thank you for your invitation to respond to the ImPACT Comparison report. Firstly, we would like to acknowledge the work and effort that you and your team have put into these reports. Tremendous efforts have been made by all involved to deal with this.

Whilst you do not wish for a detailed response from us, there is one aspect we would wish to highlight in some reasonable detail and I hope that you agree that this is appropriate. I am referring to the 'Q' factor, which reduces a complex issue of image quality to a single number combining spatial resolution, dose and noise level at the centre of rotation. We note that you do point out the limitations of the 'Q' factor in the appendices, however, it could be possible for some clincal teams to take this factor and regard it as a categorical statement regarding dose efficiency. Since this places the Volume Zoom in a ranking amongst different manufacturers in a poor position, we believe that the performance of this system in delivering outstanding clinical images is not properly reflected in this ranking.

In the following, our own Physicists have commented on several possibilities to increase the Q-value by alternative choices of protocol parameters. The results are summarised in the following table, further supporting information is detailed below this.

	Impact Value	New Value	Rank
Standard brain:	5.8	7.0	1
Standard Abdomen	1.7	2.0	3 *)
Helical Abdomen	1.9	2.3	1

*) The number 1 in this category has a Q-value of 2.2. Given a 15% uncertainty, as quoted in the ImPACT report, the difference is not significant.

Standard Brain

1) Pre-Filtration

For head imaging, the SOMATOM VolumeZoom uses an optimized prefiltration which enhances gray/white matter contrast. This feature is not reflected at all in the corresponding Q-value. By not utilizing this optimized prefiltration the Q-value could be increased by 8.5% for a water phantom, but the clinical advantage would be lost.

2) Bowtie-Filter

The bowtie filter was recently redesigned for the VolumeZoom to achieve a more homogeneous appearance of the image towards the edge of the 50cm measurement field. This is advantageous both for body imaging and for head imaging, because the head scan field of view is not restricted to 250mm as with many competitors. Using the previous design of the bowtie filter leads to an 8% higher Q-value for body-modes and a 3% higher Q-value for head modes, at the cost of inferior image homogeneity and loss of image quality, if heads are not exactly centered.

3) Convolution Kernel

Convolution kernels used for head imaging on the VolumeZoom are designed to optimize the visual appearance of the image, e. g. the noise texture and the delineation of anatomical structures. Therefore, the standard head protocols on the VolumeZoom use a rather sharp kernel (H40). Using a smoother kernel (H20) similar to the other manufacturers, the Q-value would be increased by 8%.

Conclusion

Using the modifications discussed above, the Q-factor for brain imaging on the Volume Zoom can be increased by 21% in total (5.8 -> 7.0), changing the ranking such that the Volume Zoom is on position 1 in the list.

Furthermore, the VolumeZoom uses a dedicated image filter for head imaging. This filter reduces the image noise without degrading image sharpness, when both soft tissue and bony structures are present. It is not effective for a simple water phantom like the one used for the determination of the Q-value. Therefore the benefits of the ORA-filter are not reflected in the Q-value.

Standard Abdomen

1) Bowtie-filter

See Standard Brain, the Q-factor could be increased by 8% using the previous design of the bowtie filter, at the cost of inferior image homogeneity.

2) Convolution kernel

As discussed above, the use of different convolution kernels can increase Q. For the majority of applications, B30 is the clinically preferred kernel. Using B35, which is also available, the Q-factor can be increased by 8%.

Conclusion

Using the modifications discussed above, the Q-factor for standard abdomen imaging on the Volume Zoom can be increased by 17% in total (1.7 -> 2.0), leaving the Volume Zoom on position 3 in the list.

Helical Abdomen

1) Bowtie-filter

See Standard Abdomen. The Q-factor could be increased by 8% using the previous design of the bowtie filter, at the cost of inferior image homogeneity.

2) Convolution kernel

See Standard Abdomen. Using B35, which is also available, the Q-factor can be increased by 8%.

3) Slice collimation

Narrow beam collimation in multislice CT has several advantages: elimination of partial volume artifacts, improved definition of slice sensitivity profiles, ability to additionally reconstruct thin slices. For this reason the 4*2.5mm collimation is the default setting for standard abdominal protocols. With a wider beam collimation of 4*5mm, as chosen by other manufacturers, the geometric efficiency can be improved, resulting in a 5% increase of the Q-factor. However the benefits mentioned above would be lost.

Conclusion

Using the modifications discussed above, the Q-factor for helical abdomen imaging on the Volume Zoom can be increased by 22.5% in total (1.9 -> 2.3), changing the ranking such that the Volume Zoom is on position 1 in the list.

Inner Ear

Volume Zoom is on rank 1 in the ImPACT report.

High Resolution Spine

The kernel B60s reflects the feedback from the majority of users of the Volume Zoom. If, however, a higher resolution is desired, one can also use the kernel B70s, which is considerably sharper.

May I say that in conclusion, despite the above, we are pleased to have been able to assist in this process and keen to maintain the outstanding levels of co operation and support between our orgainsations !

We look forward to continuing to work with you in the future.

Yours sincerely

David Forrest

Product Manager CT

ImPACT Response to Siemens Comments

Siemens have made a number of comments relating to how the Q-value could be increased if certain design features on their scanner were changed in respect to filtration. We will address the three main aspects below. However, whilst we accept that Q does not reflect all aspects of image quality, for example Siemens have mentioned image uniformity, it is not appropriate to use a hypothetical Q-value in a comparison.

1) With respect to choice of convolution kernel (H20 vs H40, B35 vs. B30, B70 vs. B60), in the clinical scan comparisons our approach is to use the kernel recommended by the manufacturer. We consider that to be the most appropriate approach for clinical scan comparisons. In practice, there is obviously a range of acquisition parameters that could be used; altering these may, or may not, have a bearing on Q. To address the problem of dependence of Q, the 'Dose Efficiency' section of the report compares Q-values with similar acquisition parameters, and kernels with similar MTF values.

2) The use of the ORA image filter used in head imaging is reflected in the Q-value. The phantom for determining the MTF value used in the Q equation will reflect the higher resolution obtained for sharp edges, whereas the uniform water phantom used for the noise measurements will give a noise value that reflects a smoother filter. The combination of these two figures in the Q equation results in a higher Q than would be obtained without the ORA-filter.

3) We are in agreement with the point made relating to slice collimation (Siemens letter, page 3, in that the comparisons of Q should be made for a standard collimation. However, using a wider collimation for the Siemens scanner would not alter its position in the table.

Response from Toshiba Medical Systems

Subject MS Comparison report Our reference JB/2001/25 Date May 6, 2001

Dear Sue

Below you will find Toshiba's manufacturers comment on ImPACT's Four Slice CT Scanner Comparison Report, Version 3.02. Please add this letter or its content to your official Blue Cover Version of this report.

Summary

The assessment is primarily based on an evaluation protocol for single slice Helical CT scanners. This implies that the report does not evaluate the image quality in the Z-direction, being one of the most important of Multislice CT scanners. The advantage of volumetric scanning over single slice scanning is the easy realization of isotropic volumes whereby the resolution in all directions is identical. Next to this an objective assessment of the Low Contrast detectability is missing.

General remark on the evaluation criteria for Dose Efficiency

The Dose Efficiency evaluated in the clinical sections for Standard Brain, Standard Abdomen and Helical Abdomen is performed through the Q2 formula. Although the individual parameters used in this formula have a certain relation with image quality, the combination of these factors has only a partial relation with Dose Efficiency for Low Contrast Detectability and Image Quality.

A large proportion of this Q2 value is determined by the spatial resolution of the reconstruction filter at 10 and 50 % of the MTF curve, however the 10 and 50 % frequencies of the MTF curve states something about the spatial resolution (high contrast resolution) of the applied filter. The low contrast resolution is described by the shape of the MTF curve at very low frequencies. In Toshiba's case the optimal low contrast resolution is specified as 2.5 mm @ 2.5 HU difference. A resolution of 2.5 mm can be converted to a spatial frequency of 2 LP/cm that can be detected between 80 - 90 % MTF. Therefore putting the 10 & 50 % MTF value in a formula in order to establish a figure that must have a relation with low contrast resolution is incorrect. The ImPACT measurement shows that the average of 10 & 50 % MTF of all convolution filters have approximately the same value. This means that the Q2 factor is for the largest proportion defined by the CTDIw and the noise values.

Due to the difference in reconstruction algorithms and X-ray spectra optimisation of the different manufacturers, the noise patterns differs and therefore the noise figure is not decisive for the low contrast detectability of the individual systems. Therefore we must emphasise that the Q2 value does not represent the dose efficiency in relation to the image quality in which the low contrast resolution is of the greatest importance.

Standard brain / Standard abdomen / Helical Abdomen

In the acquisition protocols of the standard brain mode, the scan time varies between 0.75 and 2.0 sec creating differences in the number of samples per image (single vs. multiple rotation acquisition) and therefore compromise between speed and image noise. In contradiction to single slice Helical scanning, the effective slice width in a Multi slice Helical scan is marginal dependent from the pitch factor. Effective slice width is determined by the incorporation of adjacent data sets, generating larger values of Z-sensitivity. This is why we separate the acquisition from the reconstruction and therefore define the beam width and image width separately. Frequently modern scan protocols use thin beam width acquisitions and thicker image width reconstruction. Therefore the Z-sensitivity is determined by the operator and not by the equipment anymore.

Reduction of motion artifacts and anatomical coverage in a single breathold enabled by the reduction in scantime is not taken into consideration.

Inner ear / High Resolution Spine

With the introduction of Multi slice scanners the emphasis of scanning is changed from axial to volume acquisition. At the moment of establishing the scan protocols it was clearly stated that the major purpose of these protocols is to acquire isotropic volumes for high quality MPR's and three-dimensional reconstruction. This type of reconstruction requires other (softer) convolution filters than those used for pure axial scanning. Therefore focussing on the limiting resolution at axial scanning for these kind of examinations is not correct. Measuring the volume resolution through scanning and reconstruction of a three dimensional object is more appropriate.

Since the slice thickness' varies between 0.5 and 1.25 mm, the applied assessment protocols do not indicate any capability of isotropic volume acquisition neither resolution in longitudinal direction.

There is no reference that the measurements are achieved at the shortest scan time with the highest sampling rate. In clinical environment the MTF is subject to deteriorate because of motion artifacts in case slower rotation speeds are used.

Hope to have you informed sufficiently, best regards

Hans Baartman

Product manager CT

ImPACT response to Toshiba's comments

Toshiba's comments relate primarily to three areas, which are responded to below:

1) Assessment of low contrast resolution (LCR)

A common approach is to use image noise as a measure of LCR. This can be objectively measured and used to compare different systems. Although we accept that for very different noise power spectra the same noise value could give very different levels of perception, ImPACT make Dose Efficiency (Q) comparisons using convolution kernels with similar MTF 50% and 10% values. Under these conditions the assumption that LCR is related to noise should be reasonably valid.

The other method commonly used for defining LCR is the subjective method of quoting the size of object perceived at a given contrast and dose level. Although this relates more directly to the clinical situation it has the disadvantage of being insensitive and subjective, with resulting problems in standardisation. ImPACT have made measurements using this methodology and the data will be presented in the individual reports on each scanner model.

2) Assessment of z-axis resolution

In the 'clinical scan tables' scans with different z-axis resolutions are compared. This reflects both what is recommended by each manufacturer and what the scanner is capable of (e.g. with high resolution scans, some scanner models can achieve a z-axis resolution of 0.5 mm whereas on others only 0.9 mm is possible). ImPACT quote the measured FWHM of the z-sensitivity profiles in the clinical scan tables. These values are a measure of the z-axis resolution; that is, the scanner's capability of isotropic volume acquisition. We accept that there may be a need to draw the readers' attention to this point.

3) Scan time used in clinical scan protocols

The scan times used in the clinical scan tables reflect what is recommended by the manufacturers for clinical use. The reader must draw their own conclusion as to the detriment of a long scan time on image quality, particularly in relation to patient movement. It is accepted that often the longer scan times will have a higher sampling rate, and therefore may be preferred to be used to obtain high spatial resolution. At the resolution levels used in Standard Brain/ Standard Abdomen/ Helical Abdomen there is no significant advantage gained in terms of resolution in using a longer scan time.

Appendix 4: ImPACT and the MDA

Background

One of the roles of the Medical Devices Agency (MDA) 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.

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

ImPACT

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

ImPACT have 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 ion chambers, and x-ray film is used to obtain additional x-ray dose information.

Members of ImPACT contributing to and writing this report: N. Keat, A. L. Hill, M. A. Lewis, J. F. Barrett and S. Edyvean (ImPACT Group Leader).

ImPACT and MDA 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.

ImPACT
Bence-Jones Offices
St. George's Hospital
London SW17 0QT

Tel: 020 8725 3366

Fax: 020 8725 3969

email: `impact@impactscan.org`

web site: `http://www.impactscan.org`

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

Debbie Smith
Programme Manager
Room 1207, Hannibal House
Elephant and Castle
London SE1 6TQ

Tel: 020 7972 8155

Fax: 020 7972 8105