



Evaluation Report

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MDA 03022

Single Slice CT Scanner Comparison Report Version 8

ImPACT report

MDA Evaluation Report

MDA 03022

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Single Slice CT Scanner Comparison Report

Version 8, February 2003

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

Manufacturer	Scanner model
GE	HiSpeed ZX/i
Siemens	Somatom Emotion
Toshiba	Asteion VR

Compiled and prepared by members of the ImPACT group

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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 produced comparison reports for the seven phases of the purchase program. The primary aim of these reports was to aid the equipment selection process by providing comparisons of CT scanners that are currently on the market. The previous set of 'Blue Cover' comparison reports generally available was from Phase 7 of the government purchase, in August 2002 (report numbers MDA 02058 (single slice), 02060 (dual), 02061 (four slice) and 02059 (eight and sixteen slice)).

Version 8 of this report was produced to reflect changes in scanners since that date, and in anticipation of the availability of further funds for CT scanner purchase within the NHS.

The scope of this report is limited to CT scanners that are capable of acquiring one set of attenuation data per tube rotation. Separate reports are available for dual, four, six to ten and sixteen slice scanners.

■ Comparison methods

The data given in this report are representative of the scanners as of February 2003, 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, performance and specification.

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.

Specification comparison

The specification comparison is presented as a side-by-side summary comparison of the specification of each scanner, workstation and related equipment. It is grouped into a series of sub-sections relating to different aspects of the scanner, such as gantry, tube and detectors etc.

■ **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. The scanner models in this report are listed in the table below. In general, the scanners are the highest specification single slice model available from each of the manufacturers.

Manufacturer	Scanner model
GE	HiSpeed ZX/i
Siemens	Somatom Emotion
Toshiba	Asteion VR

Although there are only three scanners listed in table 1, the information contained in this report is also relevant for other scanner models.

The GE HiSpeed ZX/i has the same imaging performance as the HiSpeed LX/i and FX/i scanners, but different tube and generator sizes. It also has a shorter minimum scan time and shorter reconstruction time than the FX/i.

The x-ray beam filtration on the Emotion has changed since ImpACT assessed it. Siemens have stated that it reduces the patient dose, in terms of CTDI, by 20%, and claim that the low contrast specification remains the same at this lower dose. ImpACT have not yet re-assessed the scanner with the new filtration.

The Toshiba Asteion VR is the same as the Asteion VI, which has a less powerful computer system that results in slower reconstruction times, and may be sold with a lower specification tube. The imaging performance of the scanners is identical. The performance data for the Asteion VR is taken from a Toshiba Xpress GX, which has identical imaging performance.

Scanner performance

■ 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 MDA/98/25, *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 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 50% and 10% MTF values (known as MTF_{50} and MTF_{10}) for 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 high geometric efficiency will not produce large patient doses, particularly for narrow slice thicknesses, where geometric efficiencies are normally lowest.

Clinical scan tables list 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).

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: 5 mm for head, 10mm for body.

Scan time: 1.5 or 2 s for head, 1s or faster 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 filter	mAs for 50mGy	z-sens (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	Q_2
GE ZX/i	Std+	342	4.9	0.31	3.2	6.3	6.9
Toshiba Asteion	FC21/ U05	325	4.7	0.30	3.0	5.7	6.3
Siemens Emotion*	H40s	207	5.0	0.32	3.5	5.7	6.1
Mean		292	4.9	0.31	3.2	5.9	6.4

* this result is from an earlier version of the Siemens Emotion, with different x-ray beam filtration. See page 4 for more details.

Body scanning

Scanner	Recon filter	mAs for 15mGy	z-sens (mm)	Noise (%)	MTF_{50} (c/cm)	MTF_{10} (c/cm)	Q_2
GE ZX/i	DetI	224	9.7	1.3	3.3	6.1	2.0
Siemens Emotion*	B30s	119	9.5	1.4	3.7	5.9	2.0
Toshiba Asteion	Std+	227	9.4	1.7	3.8	6.2	1.8
Mean		190	9.6	1.47	3.6	6.1	1.9

* this result is from an earlier version of the Siemens Emotion, with different x-ray beam filtration. See page 4 for more details.

■ 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 (c/cm)	MTF ₁₀ (c/cm)
Toshiba Asteion	FC80	11.2	14.5
GE ZX/i	Edge	10.2	12.1
Siemens Emotion	AH80s	7.7	10.2

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 MTF₁₀ value.

■ **Geometric efficiency**

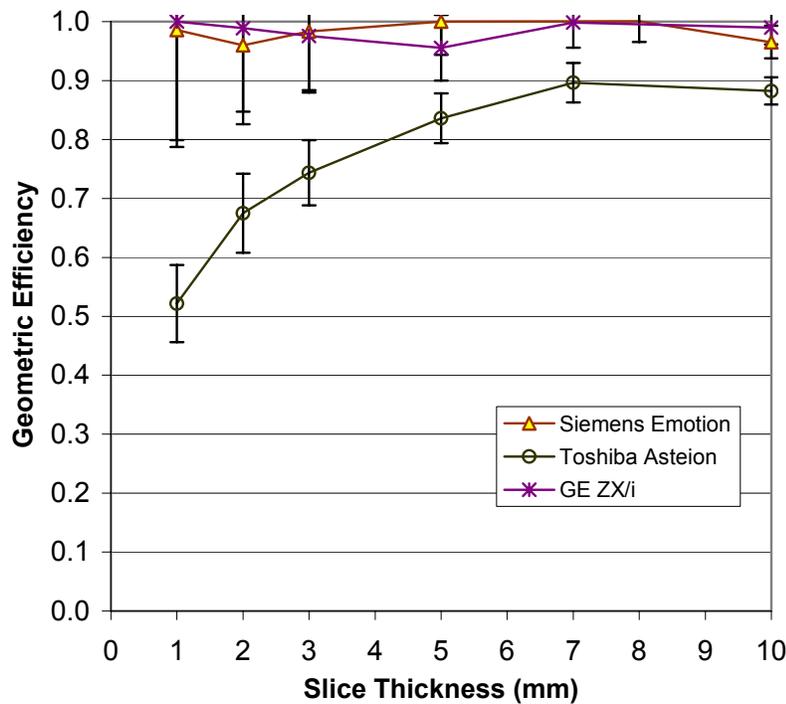
Geometric efficiency is a measure of the scanner’s dose utilisation in the z-axis. This is expressed as the ratio of the axial imaged slice section thickness relative to the z-axis dose profile. For optimum dose utilisation, the geometric efficiency should be 1, but it is often less, especially for narrow 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 are due to the accuracy limits of the measurements.

The data is presented in the form of a table of geometric efficiency values for 1mm nominal slice thickness, and a graph showing how geometric efficiency varies with slice thickness. Scanners are ranked according to geometric efficiency.

Error bars on the graph reflect the accuracy of measurements of the section thickness (± 0.2 mm) and dose profiles (± 0.2 mm).

Scanner	Dose profile (mm)	z-sensitivity (mm)	Geometric efficiency
GE ZX/i	1.4	1.4	1.0
Siemens Emotion	1.4	1.4	1.0
Toshiba Asteion*	2.3	1.2	0.5

* Data for the Toshiba Asteion was obtained at a temporary scanner installation, which may have resulted in dose profiles that are up to 15% wider than specified.



■ 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

10 mm head scan reconstructed to show low contrast brain detail. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Recon filter	CTDI _w (mGy)	z-sens. (mm)	Noise (%)	MTF ₅₀ (c/cm)	MTF ₁₀ (c/cm)
GE ZX/i	120	280	2	5	250	Std+	41	4.9	0.34	3.2	6.3
Siemens Emotion	130	255	1.5	5	250	H30s	62	5.0	0.26	3.2	5.3
Toshiba Asteion	130	195	1.5	5	240	FC21/ U05	30	4.7	0.38	3.0	5.7
MEAN							44	4.9	0.3	3.1	5.8

Standard abdomen

Axial 10 mm abdomen scan. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Recon filter	CTDI _w (mGy)	z-sens. (mm)	Noise (%)	MTF ₅₀ (c/cm)	MTF ₁₀ (c/cm)
GE ZX/i	120	175	0.7	10	380	Std+	12	9.7	1.24	2.7	4.8
Siemens Emotion	130	120	0.8	10	380	B40s	15	9.5	1.77	4.0	6.7
Toshiba Asteion	120	150	1	10	400	FC11	10	9.4	2.05	3.8	6.2
MEAN							13	9.5	1.9	3.9	6.5

Helical abdomen

Helical 10 mm abdomen scan, with pitch 1 and standard (180°) interpolator. Listed alphabetically.

Scanner	kVp	mAs (/rev)	Scan time (s)	Slice (mm)	FOV (mm)	Recon filter	CTDI _w (mGy)	z-sens. (mm)	Noise (%)	MTF ₅₀ (c/cm)	MTF ₁₀ (c/cm)
GE ZX/i	120	175	0.7	10	380	Std+	12	9.4	1.22	2.5	4.4
Siemens Emotion	130	120	0.8	10	380	B40s	15	10.1	1.95	4.0	6.7
Toshiba Asteion	120	170	1	10	400	FC12	10	9.1	1.84	3.2	5.2
MEAN							12	9.5	1.7	3.2	5.4

Inner ear (1 mm)

High contrast inner ear exam, using a 1 mm slice for good z-axis resolution. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Recon filter	CTDI _w (mGy)	z-sens. (mm)	Noise (%)	MTF ₅₀ (c/cm)	MTF ₁₀ (c/cm)
GE ZX/i	120	100	1	1	120	Edge	16	1.4	8.41	10.2	12.1
Siemens Emotion	130	135	1.5	1	120	H80s	33	1.4	5.17	7.5	10.4
Toshiba Asteion	130	195	1.5	1	120	FC82	56	1.2	6.73	9.6	11.7
MEAN							24	1.4	6.8	8.9	11.2

High resolution spine

High contrast spine examination. Listed alphabetically.

Scanner	kVp	mAs	Scan time (s)	Slice (mm)	FOV (mm)	Recon Filter	CTDI _w (mGy)	z-sens. (mm)	Noise (%)	MTF ₅₀ (c/cm)	MTF ₁₀ (c/cm)
GE ZX/i	120	170	1	3	120	Bone	11	2.9	14.26	7.5	10.1
Siemens Emotion	130	165	1.5	2	120	B80s	21	1.9	14.57	7.6	9.6
Toshiba Asteion	130	130	1.5	5	120	FC30	13	4.7	7.88	6.9	9.1
MEAN							17	3.3	11.2	7.3	9.3

Specification comparison

■ Scanner gantry

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Generation	3rd	3rd	3rd
Slipring	Low voltage	Low voltage	Low voltage
Aperture (cm)	70	70	72
Scan fields of view (cm)	18, 25, 35, 50	50	18, 24, 32, 40, 50
Nominal slice widths (mm) * = Optional	1, 2, 3, 5, 7, 10	1, 2, 3, 5, 8, 10	0.8*, 1, 2, 3, 5, 7, 10
Tilt range (degrees)	±30	±30	±30
Type of positioning lights	Laser	Laser	Laser
Accuracy of positioning lights (mm)	Info. not available	±2 mm	Info. not available

■ Patient couch

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Couch top			
Material	Carbon fibre	Carbon Fibre	Carbon fibre
Length x width (cm)	224 x 65	222 x 43	200 x 47
Horizontal movement			
Horizontal movement range (cm)	162	153	182
Horizontal movement speeds (mm/sec)	20, 100	1-100	10 or 100
Accuracy/reproducibility of table positioning (mm)	± 0.25	± 0.5	± 0.25
Scannable horizontal range (cm):			
(i) without table top extension	162	153	144
(ii) with table top extension(s)	162	153	155
Vertical movement			
Vertical movement range out of gantry (cm)	40 - 95	45 - 83	30 - 91
Vertical movement range in gantry (cm)	81 - 95	18.6	73 - 91
Minimum couch top height outside gantry (cm)	40	45	30
Weight bearing properties			
Maximum weight allowed on couch (kg)	206	200	500
Maximum weight on couch which still achieves stated performance specifications (kg)	206	200	205

■ X-ray generator

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Type	High frequency	High frequency	High-frequency
Location	Rotation assembly	Rotation assembly	Rotation assembly
Power rating (kW)	53	40	48
kV settings available	80, 120, 140	80, 110, 130	80, 100, 120, 135
mA range and step size	10 - 440 (5mA steps)	30 - 240 (1mA steps)	10 - 400 (10mA steps)
Max. mA allowed for each kV	80kV: 400mA	80kV: 228mA	80kV: 400mA
	100kV: 440mA	110kV: 236mA	100kV: 400mA
	140kV: 380mA	130kV: 240mA	120kV: 400mA
			135kV: 350mA

■ X-ray tube

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Type and make	GE Performix	Siemens Dura 352-MV	Toshiba Helicool
Focal spot size(s) (mm), quoted to IEC 336/93 standard	0.5 x 0.7, 0.9 x 0.9	0.8 x 0.4, 0.8 x 0.7	0.9 x 1.3 1.7 x 1.6
Total filtration (inherent + beam shaping filter) at central axis (mm Al equivalent)	6.32 (at 70kV)	6.4 (at 80kV)	> 2.5
Anode heat capacity (MHU)	6.3	3.5	4 (nominal) (claimed equivalence to 6.5)
Maximum anode cooling rate (kHU/min)	840	635	864
Method of cooling	Oil to air	Oil to air	Oil to forced air
Guaranteed tube life	200,000 revolutions	130,000 seconds of scanning	200,000 revolutions

■ Detection system

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Detector type	Solid state (Lumex)	Solid state (Ultra Fast Ceramic)	Solid state
Number of detectors	816 (plus 23 reference)	672	896 (plus 1 pair reference)
Option to upgrade to multi-slice (slices per rotation on upgrade)	Yes (2). £100k, 2 days.	Yes (2 or 6)	Yes (4). (not 'forklift', 3-4 days)
Nominal slice widths (mm) on upgraded scanner	2 x 0.5*, 2 x 1, 2 x 2, 2 x 3, 2 x 5, 2 x 7, 2 x 10 and 9 + 1	2 x 1, 2 x 1.5, 2 x 2.5, 2 x 4, 2 x 5, 1 x 8, 1 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

■ System start-up and calibration

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Power-on to warm-up time (mins)	3 from fully off, 1 from standby	11 from fully off, 5 from standby	2 from fully off, 0 from standby
Tube warm-up time from 'cold' to operating temperature (mins)	2	3	2 (0 in an emergency)
Time to perform detector calibrations at warm-up (mins)	Included in 2 mins tube warm up	2	1
Recommended frequency for any additional calibration by the radiographer	Every 24 hours	Advised 2 hrs post switch on	1 per week
Time to perform these additional calibrations (mins)	5	2	Up to 20
Total time from fully off to scanning in an emergency (mins)	5	5 (without check up)	2

■ Scan parameters

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Reconstruction fields of view (cm)	4.8 - 50	5 - 50	5 - 50
Nominal slice widths (mm) * = Optional	1, 2, 3, 5, 7, 10	1,2,3,5,8,10	0.8*, 1, 2, 3, 5, 7, 10
Scan times for axial scans (s) * = Partial scans	0.46*, 0.7, 1, 1.5, 2, 3	0.5*, 0.67*, 0.8, 1.0, 1.5	0.5*, 0.75, 1, 1.5, 2, 3
kV settings available	80, 120, 140	80, 110, 130	80, 100, 120, 135
mA range and step size	10 - 440 (5mA steps)	30 - 240 (10mA steps)	10 - 400 (10mA steps)
Max. mA allowed for each kV	80kV: 400mA 100kV: 440mA 140kV: 380mA	80kV: 228mA 110kV: 236mA 130kV: 240mA	80kV: 400mA 100kV: 400mA 120kV: 400mA 135kV: 350mA

■ Helical scanning

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Rotation times for helical scanning (s)	0.7, 1, 1.5, 2, 3	0.8, 1.0, 1.5	0.75, 1, 1.5
Pitches available for routine scanning (range and increment)	0.5 - 3 (0.1 increments)	1 - 2	0.5 - 13
Helical interpolation algorithms available	180° LI, z-filter interpolation	180° LI, 360° LI	180° LI, 360° LI
Maximum number of rotations in one helical run at standard abdomen parameters	99 (300 mA) 110 (270 mA) 120 (250 mA) All 0.7s scan time	100 (100 mA) 100 (150 mA) 45 (200 mA) All 0.8s scan time	72 (190 mA, ff) 115 (190 mA, 0.75s, bf) 105 (150 mA, ff) 133 (160 mA, 0.75s, bf)
Maximum continuous scan time (s)	120	80 (100 opt)	100
Starting with a cold tube, the maximum helical scan distance using a 1 mm imaged slice thickness and a pitch of 1.5	Info. not available	188 mm	Info. not available
Gantry tilt for helical scanning (degrees)	30	30	Info. not available

■ Scan projection radiograph (SPR)

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Maximum SPR length (mm)	1000	1024	1390
SPR field dimensions (mm x mm)	500 x 1000	512 x 1024	width: 240, 400, 500 length: 200 -1390
Angular positions of X-ray tube available for SPR (degrees)	0, 90, 180, 270, (any angle in 5° steps)	0, 90, 180, 270 (oblique in 30° steps)	0, 90, 180, 270 (any angle in 5° steps)
Real time image	Yes	Yes	Yes
Accuracy of slice prescription from the scanogram (mm)	± 0.25	± 0.5	± 0.25
Accuracy of distance measurements from SPR's taken at isocentre (lateral and axial directions) (mm)	± 0.25	± 0.5	< ± 1

■ **Manufacturers' performance data**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Image quality			
Resolution (lp/cm) for sharpest clinical algorithm	15 lp/cm @ 0% MTF. 13 lp/cm @ 10% MTF 8.5 lp/cm @ 50% MTF Performance algorithm, small focus, 1 sec scan time	0% MTF 15.5 lp/cm. 60 mA 130 kV 0.8sec, 1mm. Large f.s. Alg: U90s.	18 lp/cm at cut off, 14.5 lp/cm at 2% MTF, 13 lp/cm at 10% MTF, FC90, 1 sec.
Contrast resolution, smallest rod size (mm) discernable at given parameters in 20 cm CATPHAN	5mm @ 0.3% @ 9mGy. 120 kv, 70mAs, Standard algorithm, 1:1	5 mm @ 0.3% @ 15.8 mGy. 130kV, 90 mAs, 0.8 sec, 10 mm	Directly comparable data not available
CT number accuracy	Info. not available	air: -1000 ± 10 HU, water: 0 ± 4 HU	Info. not available
Dose			
CTDI ₁₀₀ (mGy/100 mAs) for axial standard brain scans at given parameters:	120kV, 100 mAs (Federal Regulation 21 CFR 1020.33)	110 kV, 8 mm slice thickness	Parameters not supplied
- centre of CTDI phantom	15	14.4	18.5
- periphery of CTDI phantom	15	15.7	20
CTDI ₁₀₀ (mGy/100mAs) for axial standard abdomen scans	120kV, 100 mAs (Federal Regulation 21 CFR 1020.33)	110 kV, 100 mA, 1 s, 8 mm slice	Parameters not supplied
- centre of CTDI phantom	4.8	4.2	5.3
- periphery of CTDI phantom	7.8	8.4	9.4
Dose profile FWHM (mm) (focal spot size in brackets)	Info. not available	1:1.3, 2:2.0, 3:3.0, 5:5.0, 8:8.0, 10:9.9	Info. not available

■ **Factors affecting image quality**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Dose			
Post-patient collimation for narrow slices	No	No	Yes
Automatic mA adjustment according to body dimensions or density during examination	Smart mA (standard)	CARE dose	Yes
Noise			
Adaptive filtration for noise reduction	Advanced noise reduction	Yes (automatic for body scans)	Yes (user programmable)
Resolution			
Quarter detector shift	Yes	Yes	Yes
Moving (dynamic/flying) focal spot	No	Yes (all scan times)	No
Number of imaging detectors	816	672	896
Sampling frequency	972 views/rotation (1388 views/s max)	1000 views/s (from 2000 acquired pairs)	1200 views/s
Artefacts			
Artefact reduction algorithms	Advanced artefact reduction (shoulder, pelvis, metallic screw correction), patient motion correction, iterative bone option	Modified beam hardening algorithms (abdomen, pelvis, shoulder), motion correction for sequential scanning	Beam hardening correction, raster artefact suppression protocol (RASP), stack scanning, automatic patient motion correction

■ **Operator's console**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Image monitor			
Diagonal dimension of image screen (inches)	21	21	21
Number of monitors at console (functions of each if > 1)	1	Standard - 1, optional - 2 consoles. Acquisition on one. Filming, review and processing on both	1
Image display			
Image area matrix dimensions	512, 768, 512 x 512 interpolated to 1024 x 1024	1024 (max)	256 (real time), 512, 512 x 1024, 1024
Usual range of CT number displayed (HU)	-1024 to +3071	-1024 to +3071	-2047 to +6043
Accuracy of distance measurements in x-y plane (mm)	Info. not available	depends on pixel size	Info. not available
Dose information			
Weighted CTDI (CTDI _w) or CTDI _{vol} displayed on console	Yes	Yes	Info. not available
Dose length product (DLP) displayed on console	No	Yes	Info. not available
Geometric efficiency displayed on console when <70%	No	>70% for all collimations	Info. not available
Hardware interface			
Control methods	Mouse, keyboard	Mouse, keyboard	Mouse, keyboard

■ **Main computer**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Make and model	Silicon Graphics O ₂	Siemens PC compatible, with array processors	Silicon Graphics O ₂
Operating system	IRIX 6.5	Windows NT	Unix
Type and speed of CPU	RU500, 200 MHz	Primergy CISC 1 GHz	R5000, 300 MHz
Amount of computer RAM (Mbytes):			
(i) supplied as standard	512	512	512
(ii) maximum	512	512	512

■ Image storage

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Hard disk storage			
Total standard hard disk capacity (Gbytes)	10	54	12
Maximum hard disk capacity (Gbytes)	37	54	Info. not available
Hard disk capacity for image storage (Gbytes and no. of uncompressed 512 x 512 images)	6 (9600 images)	18 (32,000 images)	8000 images
Hard disk capacity for storage of raw data files (Gbytes and no. of data files)	4 (1000 files)	36 (13,000 data files)	2000 files
Archive options			
Archive options	MOD (standard)	MOD (standard)	MOD (standard), CD writer (optional, not DICOM CD-R)
Capacity of a single archive disk (Gbytes and no. of images)	2.3 (12,000 JPEG compressed images or 600 raw data files)	4.1 (6500 uncompressed 512 x 512 images)	2.6 (9600 512 x 512 images - slight compression)
Time to mount an archive disk or tape (s)	5 seconds (in background operation)	Approx. 30 for a full disk (immediate if empty)	< 60 for a full disk
Archive data transfer rate (images/s)	1 (read), 0.7 (write)	2 - 3	Approx. 1

■ **Image reconstruction**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Reconstruction matrix	512 x 512	512 x 512	512 x 512
Minimum reconstruction interval in helical scanning (mm)	0.1	10% of slice width	0.1
Reconstruction times			
Time (secs) from the start of data acquisition to the appearance of the 30th image of a series:			
(i) standard axial brain scan	77 (with IBO)	45	60
(ii) axial spine scan	47	45	60
(iii) helical abdomen scan	46	32	75
Parallel processing details			
Simultaneous scanning and reconstruction	Yes	Yes	Yes
Any delay in either scanning or reconstruction when performed concurrently	No	No	No
Simultaneous scanning and routine analysis	Yes	Yes	Yes
Simultaneous scanning and archiving and/or hard copying	Yes	Yes	Yes
Simultaneous scanning and transfer to second console/workstation	Yes	Yes	Yes

■ **3D reconstruction**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
3D reconstruction on main console (MC) and workstation (WS)			
MIPs and MiniIPs (maximum and minimum intensity projections)	MC - standard, WS - standard	MC - standard, WS - standard	MC - optional, WS - standard
SSD (3D shaded surface display)	MC - standard, WS - standard	MC - standard, WS - standard	MC - optional, WS - standard
3D volume rendering software	MC - N/A, WS - standard	MC - optional, WS - standard	MC - optional, WS - standard
3D virtual endoscopy	MC - optional, WS - standard (Navigator)	MC - optional, WS - optional	MC - optional, WS - standard
MPR (multi-planar reconstruction)	MC - standard, WS - standard	MC - standard, WS - standard	MC - standard, WS - standard
Planes available in MPR	Axial, sagittal, coronal, oblique, curvilinear	Axial, sagittal, coronal, oblique, curvilinear	Axial, sagittal, coronal, oblique, curved (also 90° through curved plane)

■ Optional features

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Contrast injector	Optional	Optional	Optional
Contrast media bolus tracking	Optional (SmartPrep)	Standard (CARE Bolus)	Standard
CT fluoroscopy software and hardware	Optional (CT Fluoro & Smart recon)	Optional (CARE Vision)	Optional
Hard-copy imaging device	Optional	Optional	Optional
Radiotherapy planning accessories			
Radiotherapy planning table top	Optional Exact table or GE carbon fibre	Optional	Optional
Carbon fibre breast board	Optional	Optional	Optional
Means for attaching patient immobilisation devices and a stereotactic frame to the end of the couch	Available with Varian Exact table	Optional	Optional
Software packages on main console (MC) and workstation (WS)			
Bone mineral densitometry	MC - N/A, WS - optional	MC - optional, WS - optional (Osteo CT)	MC - optional, WS - N/A
CT angiography	MC - standard, WS - standard	MC - standard, WS - standard	MC - standard, WS - standard
Dental	MC - optional, WS - optional (Dentascan)	MC - optional, WS - optional (Dental CT)	MC - optional, WS - optional
Radiotherapy CT simulation software	MC - N/A, WS - optional	Available from 3rd party	N/A
Prospective ECG-triggered cardiac software	N/A	Optional	MC - optional, WS - N/A
Retrospective ECG-gated cardiac software	MC - N/A, WS - optional	N/A	MC - optional, WS - N/A

■ **Installation requirements**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Environmental requirements (max/min temperature, humidity) in scanner room	20-28 °C, 30-70% non-condensing humidity	18-30 °C, 15-75% relative humidity	18-28 °C, 40-80% non-condensing humidity
Environmental requirements (max/min temperature, humidity) in scanner control room	20-28 °C, 30-70% non-condensing humidity	18-30 °C, 20-85% relative humidity	16-28 °C, 40-80% non-condensing humidity
Peak heat output from system during scanning (kW)	4.1	4.7	10.6
System cooling method	Output to air	Output to air	Output to air
Air conditioning requirements for scanner room of minimum floor area	Recommended for staff and patient comfort	None	Not necessary but recommended
Minimum floor area required for the system (m ²)	18	18.5 (recommend 22)	20
Dimensions of:			
(i) Gantry (H x W x D (mm)) and weight	1850 x 1820 x 911, 1180kg	1780 x 770 x 2300, 1200kg	1760 x 1970 x 870, 1300kg
(ii) Couch (H xW x L (mm)) and weight	995 x 650 x 2240, 295kg	890 x 680 x 2260, 400kg	390 x 620 x 2390, 330kg
(iii) Supplementary units (H x W x D (mm)) and weight	Power Distribution Unit: 820 x 550 x 700, 157kg	No supplementary cabinets	Transformer: 980 x 800 x 770, 550kg
Power supply requirements	3 phase 380 - 480 V, 100 kVA	3 phase 200 - 480 V, 48 kVA	3 phase 380 - 480 V, 75 kVA

■ **Independent workstation**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Is a workstation provided?	Standard	Optional (Leonardo)	Standard (AlatoView)
Computer make and model	HP X4000	Siemens Fujitsu Pentium 4	Silicon Graphics O ₂
Operating system	Linux Red Hat 7.3	NT	Unix
Type and speed of CPU	2 x 2.2 GHz CPU	Pentium 4 (at least 1.7GHz)	R12000 300 MHz
Amount of computer RAM (Mbytes):			
(i) supplied as standard	2048	1024	256
(ii) maximum	4096	3072	1024
Total hard disk storage capacity (Gbytes):			
(i) supplied as standard	163	36	9
(ii) maximum	163	36	27
Archive options	MOD (standard)	CD-R standard, MOD (optional)	MOD (optional)
Capacity of a single archive disk or tape (Gbytes)	4.6 (9400 losslessly compressed 512 x 512 images or 700 raw data files)	CD-R: 0.65Gb (4800 compressed images), MOD: 4.1Gb (26,000 losslessly compressed images) 256x256 matrix	2.6 (9600 512 x 512 images - slight compression)
Environmental requirements (max/min temperature, humidity) for workstation	10 - 40 °C, 20 - 80 % relative non-condensing humidity at 40 °C	15 - 30 °C, 20 - 85% relative humidity	18 - 28 °C, 40 - 80% non-condensing humidity

■ **Image transfer and connectivity**

	GE ZX/i	Siemens Emotion	Toshiba Asteion VR
Speed of scanner/workstation connections to local area networks (Mbps/s)	100	100	100
Remote PC access to images on workstation	Optional	Optional	Optional
DICOM service classes provided by CT console (SCP and SCU)	Storage SCU and SCP, Query/Retrieve	Storage SCU and SCP, Query/Retrieve, Print, Modality Worklist (HIS/RIS)	Storage SCU, Print (standard) Storage SCP and Modality Worklist (optional)
DICOM service classes provided by Independent workstation (SCP and SCU)	Storage SCU and SCP, Query/Retrieve	Storage SCU and SCP, Query/Retrieve, Print	Storage SCU and SCP, Query/Retrieve, Print

Appendix 1: 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 $\pm 15\%$, with a conservative estimate of $\pm 10\%$.

Appendix 2: 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 Single Slice CT Comparison Reports

Dear Sue

Thank you, for the draft version of the report.

We are happy that the CT unit assessed was representative of the HiSpeed ZX/i CT scanner.

Kind regards

Yours sincerely

Paul Morgan

CT Clinical Scientist

■ **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.

Of course specifications are changing as each CT system evolves. For example the Emotion CT system is now delivered with a new filter which results in reduced dose. Thus, I realise it is simply not possible to provide a continuous comprehensive report with the rate of change taking place. So I think it is reasonable to recognise the work done and propose not to comment on, for example, specifications that may have changed between original report and this version of the publication in relation to each individual system.

However, whilst you do not wish for a detailed response from us, there is one general 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 clinical teams to take this factor and regard it as a categorical statement regarding dose efficiency. Perhaps I could focus on the Volume Zoom, though this would affect any system. Since this 'Q' factor 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.

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

Yours sincerely

David Forrest

Product Manager CT

■ Response from Toshiba Medical Systems

Subject MS Comparison report Our reference JB/2001/26 Date May 8, 2001

Dear Sue

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

Remarks on the evaluation criteria for Dose Efficiency

The evaluation of Dose Efficiency for 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.

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.

Inner ear / High Resolution Spine

Although the sub-header under this paragraph states that this measurement is performed for good resolution in the z-axis, no reference is made to this value and only conventional axial information is determined. The application of a Helical mode for this measurement, with overlapped reconstruction, should be more appropriate.

There is no reference that these 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 by the manufacturers recommend 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 3: 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, D. J. Platten, M. A. Lewis, J. F. Barrett and S. Edyvean (ImPACT Group Leader).

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:

Arthur Goodman
Programme Manager
Room 1207, Hannibal House
Elephant and Castle
London SE1 6TQ
Tel: 020 7972 8156
Fax: 020 7972 8105

MEDICAL DEVICES AGENCY

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