Introduction

The past few years have seen a steady rise in the technical capabilities of CT scanners, on a wide variety of fronts. The development of slip rings, fast scan times and rapid image reconstruction have allowed the development of real time CT scanning and CT fluoroscopy. ImPACT has produced a Blue Cover report (MDA/00/10) on this topic, and this article gives an overview of the technology and issues raised by its use.

Toshiba were the first to develop real time CT, and introduced it on their Xpress/SX scanner range in 1995. The ability to produce CT images that are continuously updated and reflect what is currently in the x-ray beam gives rise to a number of possible applications. The most important one is CT fluoroscopy, where the real time images are used to guide interventional procedures such as lesion biopsy and drainage (figure 1). The other main application is in the timing of contrast medium studies, where the time between the injection of the contrast medium into the patient and attaining optimal contrast within the organ being studied can vary widely from patient to patient. Using real time CT, a region of interest can be used to monitor the mean CT number within the organ of interest; when it reaches a pre-set threshold, the conventional scanning can start.

Real time CT is generally performed at a low tube current, e.g. 30-70mA. Images are usually reconstructed on a 256x256 matrix, with frame rates of up to 12 per second. For CT fluoroscopy, additional hardware is required to initiate exposures and to move the table – usually this consists of a foot switch, or bed mounted control. A monitor for viewing the CT fluoroscopy output is also required in the scanner room. Real time CT and CT fluoroscopy are often sold as separate packages, so the purchase of a system with real time capabilities does not necessarily imply that CT fluoroscopy will also be available.

Figure 1. Sequence from CTF biopsy showing biopsy needle and lesion (reproduced by permission of K. Katada, Fujita Health University, Japan)
### Production of real time CT images

Real time CT scanning requires rapidly updated images; the original Xpress/SX gave three frames per second, and more recent scanners can produce up to twelve frames per second, as is the case with the Toshiba Aquilion. The fastest reconstruction times for conventional CT images are in the region of half a second, so some simplifications have to be made for real time reconstruction. Firstly, the real time CT image is usually reconstructed on a 256×256 matrix, rather than the standard 512×512 matrix used as standard in conventional CT. Secondly, the reconstruction algorithm makes use of the fact that each image in a sequence shares a lot of the scan projection data that made up the previous images in that sequence. For example, on a scanner with a one second tube rotation time, that produces six real time images per second, any one image is reconstructed from 360° of data, but only 60° of this data is newer than the data used to produce the previous image. In order to produce this image, the back-projected data corresponding to the first 60° of rotation can be subtracted from the previous image and the 60° of back-projected data that was acquired after the scan added (see figure 2).

Other simplifications may also be made to speed the reconstruction process; for example, beam hardening and other corrections may not be made. One point worth noting, though, is that in order to rapidly produce images that most closely represent the object that is in the beam, the frame rate is not the most important factor. Each image is produced from 360° of data, so, using the example of the six frames per second scanner as before, the image on screen represents what was in the x-ray beam for the previous one second plus the reconstruction time (approximately one sixth of a second). Improving the scan speed, rather than the reconstruction time is the only way to significantly reduce this lag.

![Diagram](image-url)

**Figure 2. Production of real time CT images by partial reconstruction**

### Comparison of the manufacturers’ systems

All the CT scanner manufacturers now offer real time CT systems, most of which provide similar functions. Table 1 lists the main details of each system.

All systems offer broadly the same basic features for real time CT; foot pedal control of exposure, joystick control of couch movement, operation at 120 kV and approximately 50 mA as standard, in-room display monitors, output to video and reconstruction on a 256×256 matrix at six or more frames per second. The systems that expand on this base specification are as follows:

- The GE system displays the cumulative weighted CTDI from the exposure on the scanner control console. This is useful information when calculating and considering patient doses.
- The Philips system reconstructs its images on a 512×512 matrix. This potentially increases the limiting resolution of the system, but in real time CT, the pixel size is less of a problem than in conventional CT scanning.
- The Toshiba scanners have the ability to store the real time images on hard disk, to view at a later time, rather than using a video recorder. GE’s SmartView system also offers this facility, but only for the last 100 images in a sequence.
- The MULTI versions of Toshiba’s Asteion and Aquilion scanners can monitor three parallel slices continuously. This can be helpful when trying to locate the tip of the needle in the z-direction. Other manufacturers are thought to be working on similar features.
- GE, Siemens and Toshiba all have tube rotation times of less than 1 second, with the Toshiba Aquilion fastest at 0.5 seconds.

### Table 1. Summary of real time CT scanner systems

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Scanner</th>
<th>Real time system</th>
<th>Usual kV</th>
<th>Usual mA</th>
<th>Rotation time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>CT/i, FX/i, LX/i, ZX/i</td>
<td>SmartView</td>
<td>120</td>
<td>50</td>
<td>0.8</td>
</tr>
<tr>
<td>Marconi / Elscint</td>
<td>CT Twin / MX Twin</td>
<td>CTScope</td>
<td>120</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>Marconi</td>
<td>PQ Series</td>
<td>Continuous CT</td>
<td>100 / 120</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Philips</td>
<td>Tomoscan AV range</td>
<td>BiopsyView</td>
<td>120</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Siemens</td>
<td>Plus 4</td>
<td>CARE Vision</td>
<td>120</td>
<td>50</td>
<td>0.75</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Asteion, Aquilion</td>
<td>Aspire CI</td>
<td>120</td>
<td>30-50</td>
<td>0.75 / 0.5</td>
</tr>
</tbody>
</table>
Implications for patient and operator dose

Dose to Patient

For the patient, the dosimetry associated with real time CT is broadly the same as conventional CT. However, there are differences in two main areas; firstly, the tube current is low, at around 50 mA, compared to 150-300 mA for a conventional abdomen scan; secondly, the irradiation is concentrated in a smaller area than for a conventional CT examination. This concentration of the dose can give rise to larger local skin doses.

A study of published papers presented in the Blue Cover report on real time CT found a typical scanning time for a CT fluoroscopy biopsy or drainage procedure to be approximately 120 seconds. Reported screening times vary widely, from 5 to a maximum of 660 seconds. This wide variation is due to differing techniques, levels of operator experience and workloads studied, as well as the levels of difficulty of individual procedures.

Table 2 gives estimated patient skin dose rates and effective dose rates using the operating parameters given in table 1. The skin dose rates are given by the dose rates measured at the periphery of a 32 cm diameter Perspex body CTDI phantom. A correction has been applied to give dose to muscle rather than air. The effective dose rates are calculated using data from NRPB report SR250, for scans at mid abdomen level (300mm level on SR250 phantom), with scanner matchings provided by the ImPACT CT Scanner dose survey (see http://www.sghphy.demon.co.uk/dosesurv.htm). The slice thickness used is 10 mm.

The quality of the images produced using these recommended scan parameters has not been assessed, so a scanner producing a higher dose rate could possibly be operated with lower exposure parameters, and vice versa.

With the exception of the two Marconi scanners, the skin dose rate for real-time CT is in the range of 4-5 mGy/s. Using the typical CT fluoroscopy scan time of 120 s produces a total skin dose of approximately 500-600 mGy. The maximum reported scan time of 660 seconds would give a skin dose of up to 3 Gy. Bearing in mind that the thresholds for skin erythema and temporary epilation are approximately 2 and 3 Gy respectively, there is a potential for deterministic radiation effects from lengthy CT fluoroscopy procedures. The effective dose from a typical CT fluoroscopy procedure is in the region of 6-8 mSv, which is in the same range as a typical conventional CT abdomen examination.

Table 2. Estimated Patient Dose Rates from Real-time CT Scanning

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Skin Dose Rate (mGy/s)</th>
<th>Effective Dose Rate (mSv/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE HiSpeed CT/i</td>
<td>4.7</td>
<td>0.048</td>
</tr>
<tr>
<td>Marconi MX Twin</td>
<td>1.6</td>
<td>0.026</td>
</tr>
<tr>
<td>Marconi PQ Series</td>
<td>7.0</td>
<td>0.060</td>
</tr>
<tr>
<td>Philips AV</td>
<td>4.1</td>
<td>0.062</td>
</tr>
<tr>
<td>Siemens Plus 4</td>
<td>4.9</td>
<td>0.066</td>
</tr>
<tr>
<td>Toshiba Asteion</td>
<td>4.0</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Audible alarms that sound after a pre-set time limit are included with all real time scanners, although the time limit is not standardised. For conventional image intensifier fluoroscopy systems, the time limit is 5 minutes, with a maximum skin dose rate of 100 mGy/min. As the skin dose rate from real time CT is 2-3 times higher than this, a similar skin dose limit for CT fluoroscopy would imply an alarm that sounded after 100 seconds.
Location | Dose Rate (µGy/s) | Dose for typical 120s procedure (mGy) | Number of procedures for 3/10 Dose Limit
--- | --- | --- | ---
Skin (hands, in x-ray beam) | 3-4 mGy/s | n/a | n/a
Skin (hands, with needle holder) | 17 µGy/s | 2 mGy | 75
Body Trunk (above lead apron) | 9 µGy/s | 1 mGy | 6
Eyes | 1.5 µGy/s | 0.4 mGy | 375

Table 3. Scattered dose rates to equipment operator from real time CT
(Exposure parameters: 120 kV, 50 mA)

Dose to Operator
CT scanning does not normally involve dose to the equipment operator, who is in a separate control room. However, CT fluoroscopy procedures are interactive, and require the operator to be in the scanner suite. Considerable doses can be accumulated, especially to the skin of the hands, when conducting multiple procedures. A variety of techniques can be employed to avoid these doses, the most important of which is to ensure that the hands are out of the beam when the scanner is operating. The tightly collimated x-ray beam on a CT scanner means that the dose rate drops very rapidly away from the scan plane, and the use of a pair of forceps to manipulate the biopsy or drainage needle from a distance will greatly reduce the dose rate to the hands.

Table 3 gives scattered dose rates measured by ImPACT on a Toshiba Xpress/GX scanner from real time scanning. Measurements on a Siemens Plus 4 scanner yielded similar results. The dose rates given in table 3 are obviously highly dependent on the position of the operator relative to the scanner. The column estimating the number of procedures that could be performed at these dose rates before 3/10 of the relevant dose limit was reached shows that the dose to the operator’s trunk is the most relevant. This is the dose above which registration as a classified radiation worker would be necessary (assuming no other occupational exposure). M. Ozaki (in Medical Review No 53, 1995: Development of a Real-Time Reconstruction System for CT Fluorography) states that the use of a lead apron reduces the dose rate by a factor of 14 for 120kVexposures, which would mean that dose to the skin and the body become equally important in order to keep within dose limits.

The above examples of patient and operator dose are obviously theoretical, and are included to give an idea of the magnitude of the doses produced by real time CT. Careful monitoring of both patient and operator are required to assess the doses in real clinical practice.

In Conclusion
Real time CT has already been shown to be a valuable tool, aiding potentially difficult interventional procedures and improving the quality of contrast studies. The number of scanners that have real time capabilities is rising rapidly as it becomes more of a standard feature on new CT systems.

As real time CT becomes more widespread, the range of applications is likely to rise, as will the potential for sizeable skin and body doses to both patient and operator. Monitoring the doses to both of these groups is important. Measures to reduce the doses to both the patient and operator, such as ensuring that the exposure time is kept to a minimum as well as the use of lead aprons, needle holders, and the possible use of thyroid shields and lead glasses for the operator, should be carefully considered before introducing it into clinical use in any institution.