EVALUATION OF A NEW TYPE OF DIRECT DIGITAL RADIOGRAPHY MACHINE

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Objective. To evaluate a recently developed low-dose, large-field, direct digital X-ray scanning system for medical use.

Method. Radiation dose, image quality, diagnostic capability and clinical utility of the unit were compared with those of conventional radiography.

Results. Radiation doses ranged from 3% to 5% of conventional radiographic values, and a mean of 1 line-pair per millimetre could be detected. Ease of use, anatomical coverage and tolerance to patient motion were advantages. However, image quality was inferior to that of conventional radiographs, with limited fine detail visibility and penetration. Only 67 of 156 (42.9%) pathological features seen on conventional radiographs were detected, including 13 of 41 fractures (31.7%) and 11 of 18 pneumothoraces (61.1%).

Conclusion. Although image quality and diagnostic performance were not ideal, potential roles in triage, foreign body detection and possibly screening were promising. Radiographic factors may have affected sensitivity. This machine demonstrated useful attributes that may, with improvement, be beneficial in the imaging of trauma and other patients.

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The advantages of digital information technology, together with the greater tolerance to a range of radiation exposures of digital detectors, have led to significant recent interest in digital radiography.[1-3] A variety of direct and indirect methods of digitally capturing X-ray photons as they exit the human body have been used, but so far none has proved ideal.[4-7]

A low-dose, whole-body digital X-ray scanning security system (known commercially as Scannex) was recently developed. It uses X-ray doses of under 6 micro-Sieverts — less than the average natural daily background exposure in the UK,[8] or approximately one-twentieth of the conventional X-ray dose.

As this technology was thought to have medical applications, a more versatile 'Modified Scannex' machine was built to allow a pilot study including both medical physics and clinical testing. Alternative clinical applications arising from the device's unique combination of features were also explored.

MACHINE CONSTRUCTION

The entire unit (Fig. 1) consists of (*i*) the X-ray scanner; (*ii*) a viewing and operating console; and (*iii*) an electronics cabinet. An X-ray tube and detector array are mounted at either end of a C-arm (Fig. 2), forming the scanning arm. An integral carbon-fibre bed supports the supine patient over the detector array (Fig. 3). A thin, transversely orientated fan-beam of X-rays is directed vertically through the patient onto the detector array.[1,9,10] The scanning arm traverses the full length of the bed during radiation, producing a direct digital image in 10 seconds. The X-rays are adjustable from 60 to 160 kVp; no scanning equalisation[1] is used. There are 2 000 transverse pixels, with 14 bits of contrast resolution. The image is displayed on a 35 cm high-resolution monitor (Model M212H5S01; Image Systems) (Fig. 1), using a

Fig. 1. Components of the 'Modified Scannex' digital radiography unit, showing user console with viewing and operating display monitors (curved arrows). The patient bed (broad arrow), scanner housing (long arrow) and electronics cabinet (short arrow) are also seen.

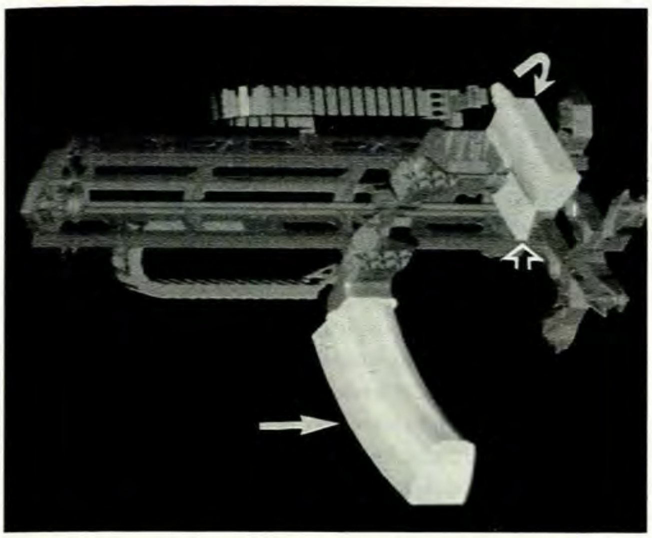

Fig. 2. *Diagram of the X-ray tube housing (curved arrow), X-ray collimator (open arrow) and detector array (closed straight arrow) mounted on a C-arm.*

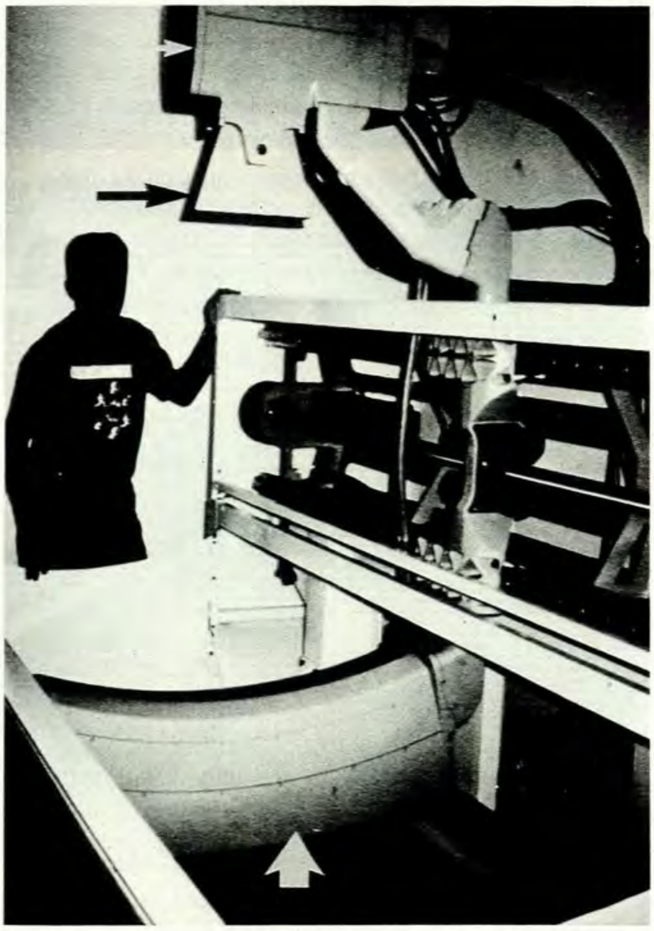

Fig. 3. *Unit after removal of patient bed and machine housing showing detector array (broad arrow), X-ray tube housing (small white arrow) and collimator (black arrow).*

screen driver displaying 256 grey levels. Interactive trackball and menu controls permit window level and width adjustment, together with display of patient identification information.

METHOD

Detailed image quality testing and radiation dose measurement using standard medical physics equipment and techniques were undertaken.

A variety of clinical conditions in consenting patients were imaged by both conventional and digital radiography, with an emphasis on subtle pathology.[11] The user interface, image quality, diagnostic performance and potential impact on clinical protocols were evaluated. Images on the monitor were compared directly with conventional radiographic images by a radiologist (SJB) with 10 years of experience. Access to clinical information was permitted. Observations were recorded on both a case-by-case and feature-by-feature basis, and rated as worse than, equal to, or better than the conventional radiographs. As free-form observations were recorded, sensitivities[12] rather than receiver operating characteristic (ROC) curves[13] were derived.

RESULTS

Medical physics

The overall radiation dose was very low, both in the direct beam and from scattered radiation. The mean entrance surface dose to the patient was 6.2 micro-Sieverts, approximately 3% (range 0.3 - 13%) of the standard conventional dose. The mean dose to staff adjacent to the X-ray unit was 0.64 micro-Sieverts, 3% of that for conventional X-ray machines. Average effective doses for abdomen, skull and chest examinations were approximately 5% of those for conventional X-ray techniques. A mean of 1 and a maximum of 1.3 line-pairs per millimetre (lp/mm) were detectable.

Clinical evaluation

Both radiographic and medical staff found the unit easy to use after approximately 30 minutes of tuition. Image retrieval and manipulation were satisfactory, although the user interface was felt to require simplification.[14,15]

A total of 65 trauma, medical and paediatric patients were evaluated between May 1996 and July 1997 (Table I). Patient ages ranged from 0 to 86 years, with a mean of 36 years. The average interval between conventional and digital imaging was 33 hours. However, only conventional and digital images taken within 10 hours were permitted for assessment of surgical emphysema and lung opacification, while for a pneumothorax the interval was required to be less than 5 hours. Alternatively, conventional images showing the pathological features both before and after the digital image were acceptable.

Table I. Disease aetiology

Gunshot wound	21	32.3%
Stab wound	14	21.5%
Motor vehicle accident	13	20.0%
Fall	3	4.6%
Blunt injury — other	2	3.1%
Other conditions	12	18.5%
Total	65	100.0%

On a case-by-case basis, the digital machine performed as well as conventional radiography in 26 of 64 cases (40.6%), while in 1 case (1.6%) digital imaging was superior to conventional radiography (Table II).

Digital performance was equal to that of conventional radiographs in 67 of 156 (42.9%) specific pathological features, and in 20 (12.8%) it provided additional information compared with conventional imaging. The digital images allowed detection of 13 of 41 fractures (31.7%), 11 of 18 pneumothoraces (61.1%), 11 of 16 examples of surgical emphysema (68.8%) and 13 of 24 areas of lung opacification (54.2%). All haemothoraces were seen (Table II).

Image quality was subjectively rated as moderate. In view of the unfavourable rating of the digital images despite access to conventional images and clinical details, further image evaluation was not undertaken. Examples illustrating diagnostic issues are presented (Figs 4 - 8).

Digital image processing appeared subjectively beneficial, in particular unsharp-mask subtraction for fracture detection.[1,16-18] The roles of image compression and picture archival were not specifically addressed.

DISCUSSION

Rapidly acquired, large-field digital radiographs of moderate quality combined with exceptionally low radiation dose to patients and staff were considered to be the most important advantages of the unit.[19-21] The doses required were of the order of 6 to 10 micro-Sieverts. This is compared with typical effective dose equivalents (in micro-Sieverts) of 50 for chest, 1 400 for abdominal, 2 100 for lumbar spine and 7 700 for barium enema examinations.[22]

The digital radiographic depiction of fractures,[2] pneumothoraces[23] and lung disease was judged clinically suboptimal in this study. Rib fractures that were readily visible on conventional radiographs were only detected in 5 of 13 instances (38.5%). Specific further areas of difficulty were the cervicothoracic junction, the lateral lumbar spine and the pelvis, where penetration was inadequate.[24] The lack of a horizontal-beam lateral view excluded lateral projections in patients who could not safely be rolled into a lateral decubitus position.

In addition, finer details that may lead to specific conditions being considered could not always be visualised.[25] In one case, degenerative shoulder joint changes could not be determined clearly, although the joint was seen to be abnormal. In 2 patients with bladder tumours, a subtle indentation of the bladder contour in one case and a papillary tumour configuration in the other could not be resolved on the digital images.

The lack of dedicated radiographic positioning on the digital equipment may have reduced the detectability of some features. The supine position used in all patients on this digital machine is known to reduce detection rates of pneumothorax,[25-32] pleural fluid[33] and subphrenic air. However, differences in positioning may also have improved detection in some cases. Reporting from

Table II. Radiographic results

	Disease present: conventional	True positive: digital	%	Binomial distribution	Digital additional	%	Total disease
Patients	64	26	40.6	—	1	1.6	65
Specific features							
Fractures	41	13	31.7	0.014*	4	9.8	45
Rib fractures	13	5	38.5	—	2	15.4	15
Skull fractures	2	0	0.0	—	0	0.0	2
Pneumothorax	18	11	61.1	0.239	2	11.1	20
Haemothorax	7	7	100.0	0.010*	0	0.0	7
Pneumomediastinum	3	2	66.7	—	1	33.3	4
Surgical emphysema	16	11	68.8	0.100	2	12.5	18
Extraluminal air	2	1	50.0	—	0	0.0	2
Opacification	24	13	54.2	0.460	3	12.5	27
Bullae	6	0	0.0	0.021*	0	0.0	6
Other	55	18	32.7	0.007*	9	16.4	64
Total	156	67	42.9	0.048*	20	12.8	176

*$P < 0.05$.

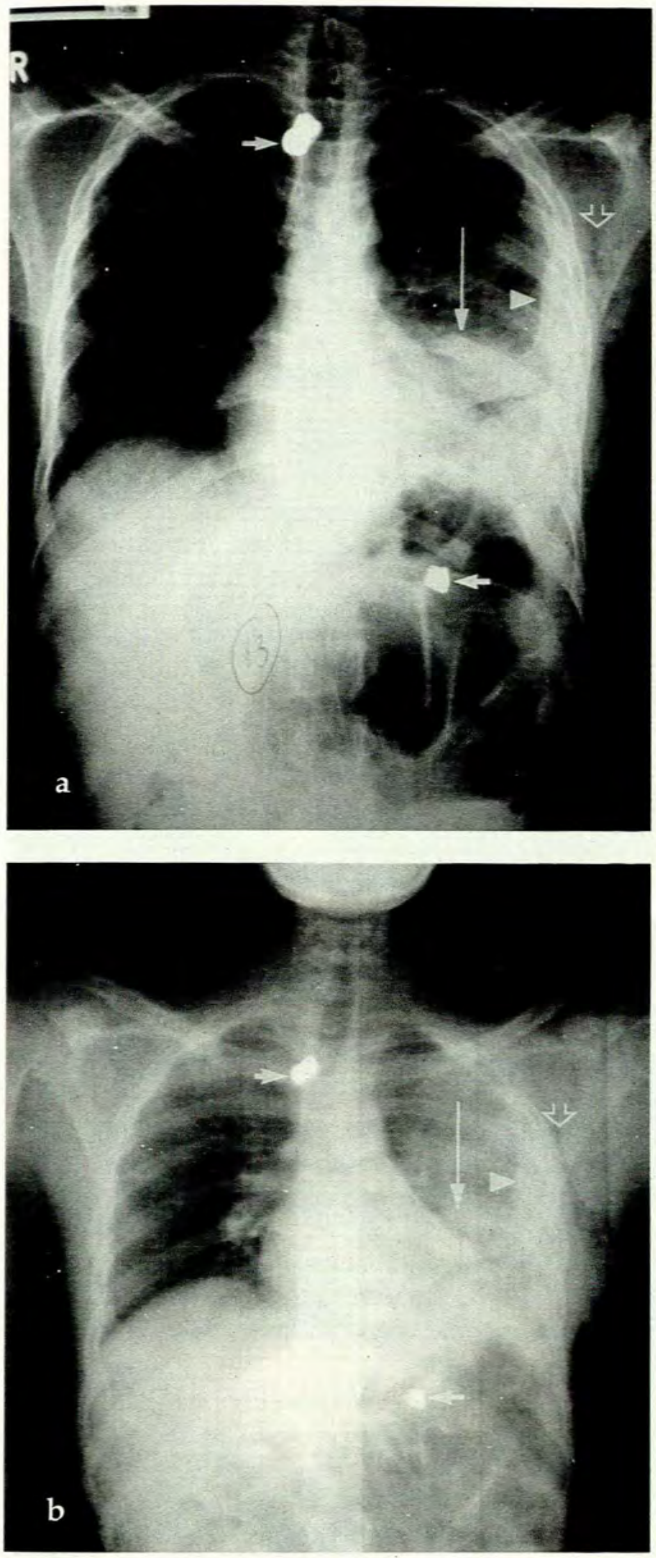

Fig. 4. Conventional (a) and digital (b) radiographs of a patient following a gunshot wound, showing bullets (short arrows), pleural fluid (arrowhead), lung opacification (long arrow) and surgical emphysema (open arrow). Vertical linear bands are due to a 'butting' artefact arising from the method of detector construction.

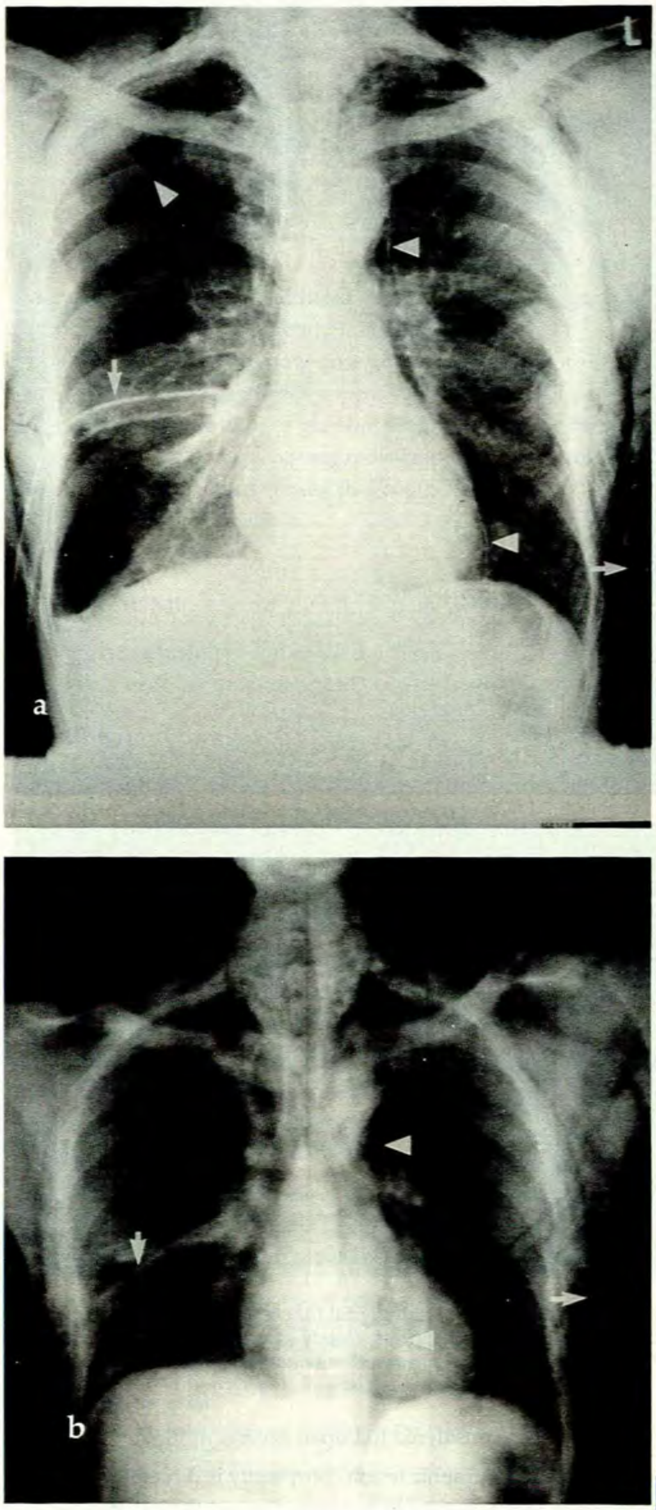

Fig. 5. Conventional (a) and digital (b) radiographs in a patient following a stab wound to the chest, showing pneumothoraces (arrowheads) and intercostal chest drains (short arrows), with the left misplaced in the subcutaneous tissues. Note that the right apical pneumothorax is not visible on the digital radiograph. Retrocardiac structures are better visualised on the digital image. Also present is extensive surgical emphysema.

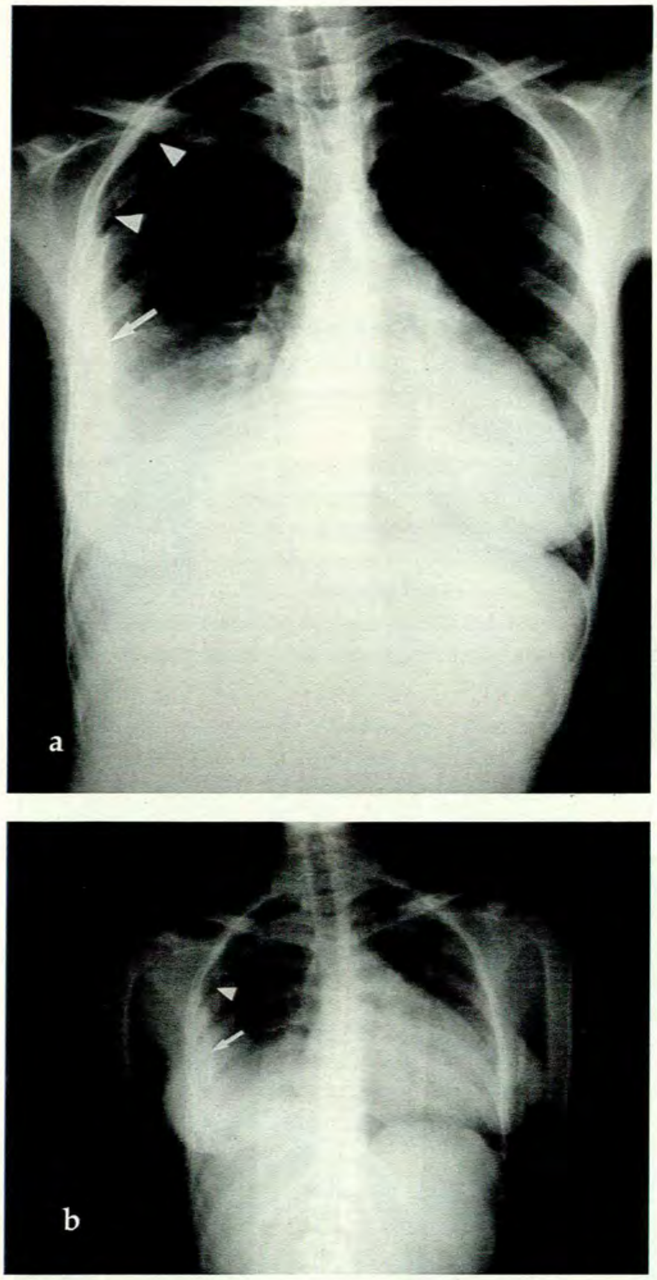

Fig. 6. Conventional (a) and digital (b) chest radiographs of a patient with a stab wound to the chest, clearly showing right-sided pleural fluid (short arrow) and pneumothorax (arrowheads).

monitors is also considered to impair accuracy.[1,34-39]

Although radiographic lesion conspicuity is difficult to define in technical terms, the study confirmed one of the initial theoretical concerns regarding lack of spatial resolution. With approximately 1 000 pixels used across the average chest, this is one-half of the 2 000 (or 2.5 line-pairs per mm) generally thought to be required.[1,40-44] Conventional chest radiography captures information at 5 lp/mm or better;[1] conventional skeletal imaging can detect up to 12 lp/mm,[2] although these resolutions are in

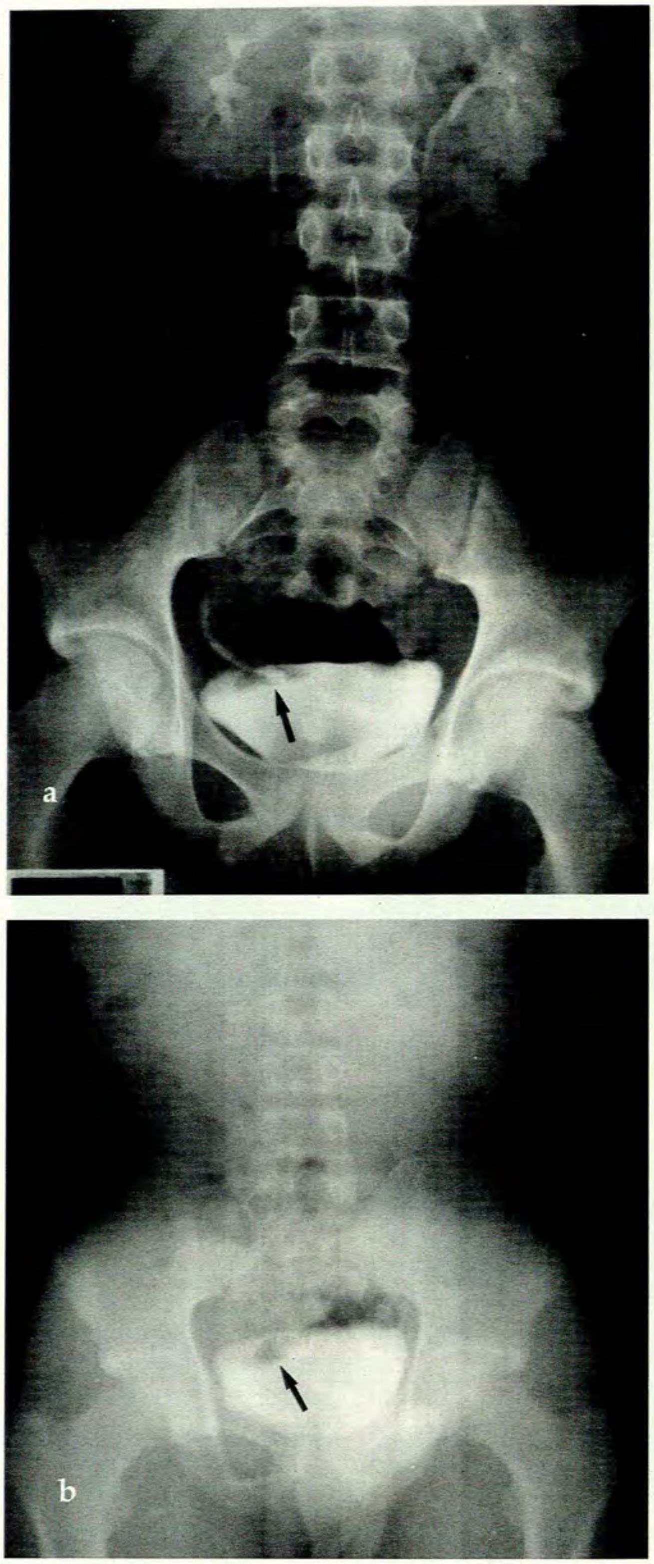

Fig. 7. Conventional (a) and digital (b) abdominal radiographs following intravenous pyelography, demonstrating a filling defect (arrow) at the right ureterovesical junction. Note the poorer demonstration of the pelvic bony detail on the digital image.

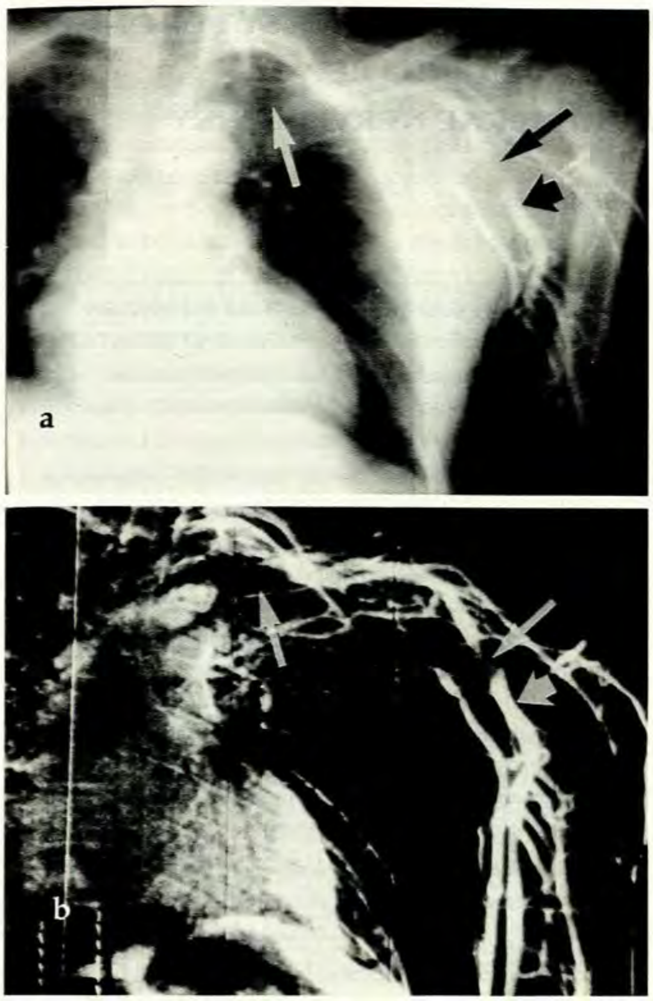

Fig. 8. Digital radiograph of upper limb venography before (a) and after (b) digital subtraction. Note the improved visualisation of the veins (broad arrow) and areas of venous obstruction (medium arrows) on the subtracted image (b).

excess of that required. An increase in radiation dose should improve image quality, although reduction in detector element size may also be needed.

Gas-filled structures such as the airways were well demonstrated. The machine was tolerant to large patient movements, which produced only slightly bowed appearances on the image.[9,45]

The use of the unit for metallic foreign body detection (particularly for bullets, where the possibility of bullet migration or embolisation exists) and trauma triage was encouraging, potentially obviating multiple conventional radiographs. The same overview technique is possible with computed tomography scan localisation systems, although spatial resolution is less than 1 lp/mm.[1,46] A role in screening may exist. Previous publications have proposed digital imaging in a trauma service,[47,48] including an emphasis on dose reduction.[49]

Two arteriograms and two venograms, including digital subtraction angiography, were of reasonable quality (Fig. 8). As the speed of movement of the scanning arm is coincidentally fairly close to that of a vascular contrast medium bolus, this could facilitate vascular applications. Practical difficulties include the lack of real-time visualisation and the timing of the scan.

CONCLUSION

The quality of the images produced on the 'Modified Scannex' digital X-ray machine is currently less than that required by some clinical imaging tasks. This low-dose and convenient digital radiology imaging system does appear suited to triage of patients with multiple injuries and/or gunshot wounds, allowing the more selective use of conventional radiographs. The technology is felt to have substantial promise that could lead to new, clinically relevant applications.

ADDENDUM

A wholly redesigned version of the machine, known as LODOX, has recently been commissioned at Groote Schuur Hospital for clinical evaluation. This is intended to meet the quality requirements of medical radiology at low radiation doses, and features selectable spatial resolution, high contrast resolution and the ability to acquire oblique or lateral projections.

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