



## Digital X-rays come of age

In early November 1895 Willem Röntgen performed an experiment in which invisible cathode rays, generated by electrostatic discharges from within an evacuated glass tube, caused a cardboard screen painted with barium platinocyanide to fluoresce. Although the new rays would also come to bear his name, Röntgen called them X-rays, apparently using the mathematical designation for something unknown.<sup>1</sup> While investigating the ability of various materials to stop the X-rays, he stepped into the line of the rays to introduce a piece of lead and was startled to see an image of his own skeleton shimmering on the fluorescent screen. His groundbreaking article<sup>2</sup> was published less than 2 months later on 28 December 1895 (the peer-review process has clearly slowed things down in the past 111 years!).

Before the middle of the following year portable X-ray machines, costing just \$15 and used in conjunction with a photographic plate, were recording images for diagnostic purposes all over the world.<sup>3</sup> Although Röntgen died of bowel cancer in 1923, it is generally believed that the carcinoma was not the result of his work with ionising radiation. This belief stems from the fact that he routinely used a protective lead shield during his experiments.<sup>1</sup> But of course X-rays are not only carcinogenic, they can also be employed to treat cancerous tumours. The first documented treatment was performed by a German physician named Voight who treated a patient for nasopharyngeal cancer on 3 February 1896.<sup>4</sup>

It was 50 years ago, in the first half of 1956, that Allan Cormack, a young lecturer in the Physics Department at the University of Cape Town (UCT), was seconded to Groote Schuur Hospital for a day and a half per week. As the only nuclear physicist in Cape Town, his responsibilities were to manage the radioactive isotope programme and to set up a film-badge monitoring service. Even though it was not part of his job, he could not help being intrigued by the planning of X-ray treatments. The planning at Groote Schuur was probably as good as any in the world, but Cormack was struck by what he saw – to a physicist the procedures appeared to be *ad hoc* and the numerical calculations were very approximate. He felt there had to be a better way to estimate the densities of the underlying tissues, and so he took this problem back to the laboratory in the physics department.

Instead of X-rays Cormack substituted gamma-rays, and in order to acquire his data in digital form he replaced the photographic plate with a Geiger counter. His mathematical solution to the problem, published a few years later in 1963, laid the foundation for the computer-assisted tomographic (CAT) scanner.<sup>5</sup> The first clinical CAT scanner was introduced by the English engineer Godfrey Hounsfield<sup>6</sup> at the Atkinson Morley Hospital in London in 1972 and within a few years there were half a dozen manufacturers and hundreds of scanners

in daily use around the world. The CAT scanner was the first widespread application of digital X-rays and has had a major impact on the practice of medicine in the past 3 decades. And so Röntgen, who was awarded the first Nobel Prize for Physics in 1901, was followed by Cormack and Hounsfield who shared the Nobel Prize for Medicine in 1979.

Digital technology subsequently had a profound impact on other imaging methods, most notably ultrasound and magnetic resonance imaging. Paradoxically, the modality that has most resisted the digital acquisition route has been plain X-rays. Computed radiography (CR) – where the image is captured on a phosphor plate and read out digitally on a laser scanner – has provided an interim solution, while direct acquisition sensors, with an area comparable to standard X-ray plates, are still prohibitively expensive.

De Beers, through its subsidiary the Diamond Trading Company, currently has total sales (i.e. turnover) approaching 10 billion US dollars per annum. In the late 1980s it estimated that between 10% and 20% of its uncut diamonds were being purloined by workers. Clearly something had to be done! Their solution was to develop and patent a whole-body scanning system based on digital X-ray technology.<sup>7</sup> Because the system had to comply with international radiation exposure guidelines, and the safety of its diamond workers was of paramount importance to De Beers, their engineers were able to design a system that utilised an extraordinarily low dose of X-rays. Not only could their scanner pick up diamonds, it also exhibited great potential for medical diagnosis. The original clinical scanner, dubbed Lodox (for **low dose x-rays**), was developed by a team led by Herman Potgieter and installed at Groote Schuur Hospital in the mid-1990s. The system was first described in this *Journal* by Beningfield *et al.*<sup>8</sup>

De Beers, using input from clinicians, scientists, engineers and radiographers from Groote Schuur and UCT, set about optimising the system for use in a busy trauma unit. The initial focus was on this area because violence and road traffic accidents constitute two of the top five causes of premature mortality in South Africa.<sup>9</sup> The challenge was to devise a system that was diagnostically equivalent to existing conventional analogue X-ray systems, while maximising the access to resuscitation and minimising radiation exposure of both patients and staff. The second prototype of the Lodox clinical scanner was commissioned in July 1999 and shortly thereafter the world's first whole-body digital X-ray was acquired of a patient who had been injured in a motorbike accident. One single image, viewable on a computer screen, clearly showed multiple fractures, including those of the skull, radius, ulna, pelvis, femur, tibia and fibula.

The first clinical trial<sup>10</sup> confirmed that the images were diagnostically equivalent to analogue X-rays. There were two



other major benefits: first, the turnaround time was drastically reduced (6 v. 48 minutes for patients requiring resuscitation); and second, the radiation dose was reduced by on average 90% (0.03 v. 0.57 rads). Turnaround time was decreased because the Lodox system is able to acquire a single image of the whole body (as opposed to multiple dedicated views for conventional X-rays) and because the X-ray film does not need to be processed. In a digital world, the data are available within seconds of completing the scan. The dose reduction is primarily a result of the slot-scanning feature of the design in which a narrow 'fan' of X-rays is projected onto a digital detector that scans the patient in synchrony with the X-ray tube. Back-scattered X-rays, responsible for much of the radiation dose, are all but eliminated. Encouraged by the success of their scanner, De Beers launched Lodox Systems (Pty) Ltd in 2002, and with the help of their partners Netcare and the Industrial Development Corporation, began to market a newer version called Statscan to trauma hospitals in South Africa and around the world.

As highlighted in this issue of the *Journal*, the Lodox technology has moved beyond trauma applications to include paediatrics and forensics.<sup>11,12</sup> The combination of extremely low-dose and high spatial resolution suggested to us that the technology could also be feasible for mammography.<sup>13</sup> In a landmark article published last year in the *New England Journal of Medicine*, Pisano *et al.*<sup>14</sup> showed that digital mammograms are particularly beneficial for women who have dense breasts, as well as women who are younger than 50. Although no national screening system exists in the country, the Cancer Association of South Africa reported in 2000 that carcinoma of the breast was the most common form of cancer in women. In the USA, 32% of cancer incidence and 18% of cancer deaths are attributable to carcinoma of the breast.<sup>15</sup> Fortunately, mammograms have contributed to a 20% reduction in the breast cancer death rate in the USA in the past decade.<sup>16</sup> Our own research group was funded last year by the National Institutes of Health in the USA to develop an innovative mammography system based on slot-scanning digital X-rays.<sup>17</sup>

And so, as we stand on the shoulders of Röntgen, Cormack, Hounsfield and the engineers of De Beers and Lodox Systems, it is clear that digital X-rays have emerged as a diagnostic modality with enormous potential to contribute to management of the burden of disease in our country.

## Christopher L Vaughan

Hyman Goldberg Professor of Biomedical Engineering  
Medical Research Council/University of Cape Town Medical Imaging Research Unit  
Department of Human Biology  
University of Cape Town

Corresponding author: C L Vaughan (kvaughan@cormack.uct.ac.za)

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