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GUEST EDITORIAL

How many physicists does it take to test a mammography unit?

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I'm sorry to lure you in with a joke for which I don't have a punchline; the answer is just one, yet there are 95 physicists in Australia and New Zealand who hold ACPSEM Certification in Mammography Equipment Testing [1]. To put this into perspective, there are only 41 medical physicists who hold ACPSEM Certification in Radiology [2].

This raises the questions of why mammography is the only radiology modality to have its own certification process and why there is so much demand for this qualification. Having spent 12 years specialising in mammography physics, I'll attempt to answer these questions and look at how mammographic technology has changed over the years and how this has impacted the role of the medical physicist.

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The challenges of mammography

Mammography is defined as the X-ray examination of the breast. It is just one of the modalities used for breast imaging; ultrasound and magnetic resonance imaging (MRI) are incredibly valuable adjunct techniques and newer technologies are gradually being adopted, such as molecular breast imaging and dedicated breast computed tomography. Inevitably, we tend to associate the term breast imaging with breast screening. Although breast screening has its critics [3], there can be no doubt that breast cancer is a major health burden on a global scale; it is the second most common cancer in the world and is responsible for more female deaths than any other cancer type [4]. Within Australia, 1 in 8 women will be diagnosed with breast cancer by the age of 85 [5]. However, it is reassuring to note that mortality rates are decreasing despite the fact that incidence rates continue to rise and the diagnosis rates in young women are increasing [6].

Mammography is considered to be the gold standard for breast screening, having an overall sensitivity of about 85% and specificity of 90% [7] in women aged 50–70. Breast imaging is challenging since it is necessary to detect and classify pathological details (microcalcifications and masses) against a background of fibrous tissue, which can vary considerably in radiological appearance depending on breast thickness and composition.

Microcalcifications have a relatively high atomic number and density and hence high inherent and subject contrast. Unfortunately they are generally very small in size, ranging from 10 μm through to several mm [8]. Although masses are of moderate size (5–10 mm), detection of carcinoma is difficult since malignant tissue has negligible physical density difference from fibrous breast tissue, a similar attenuation coefficient and therefore low inherent contrast

[9]. Fortunately, malignant breast tissue does have a higher effective atomic number and mammography therefore utilises the photoelectric effect, which is proportional to Z^3/E^3, to enhance the contrast between these tissues based on this difference. Low X-ray beam energy, E, which is well-suited to soft-tissue imaging, also increases the likelihood of photoelectric interaction [10].

The demands on mammography are therefore stringent: both high spatial resolution and excellent low contrast resolution are required to detect microcalcifications and to visualise masses respectively. Additionally, radiation doses must be kept as low as reasonably achievable, a requirement which is absolutely paramount for screening where approximately 99% of the population will be cancer-free at the time of their examination.

Quality assurance in mammography

Consequently, the quality assurance requirements for mammography are also very stringent, which partly explains why we need certified mammography physicists. Compared to most radiographic imaging modalities there are more tests, tighter tolerance levels and higher testing frequencies; in NSW for example, mammography equipment must be tested on an annual basis, compared to 5-yearly for general radiographic equipment. Depending on the experience of the physicist and the complexity of the equipment, testing of a single unit can take several hours. However, as physicists we can't complain… the radiographers are doing QC on a daily basis!

During my career, the most significant change in mammography has been the replacement of screen-film by digital image receptors, with the term digital mammography encompassing both computed radiography (CR) and integrated digital radiography (DR) detectors. My career in mammography physics started in Manchester, which in 2005 became one of the first places in the UK to adopt digital mammography. It was a challenging experience for me as a very junior physicist, to carry out acceptance testing on equipment for which few QC guidelines existed and even fewer tolerance levels. I made measurements of every parameter I could think of, but with little to compare the values to, it was difficult to say whether the equipment had passed or failed! I would never have guessed that this early experience would enable me to take up a job on the other side of the world, but I'm very glad it did.

Upon arriving in Australia in 2009, I was impressed to find that a group of physicists had already published interim recommendations for digital mammography QA [11]. These physicists, along with the ACPSEM and the Royal Australian and New Zealand College of Radiologists (RANZCR) must be acknowledged for their role in the development and ongoing review of QA guidelines for digital mammography. By necessity, a new image receptor technology requires completely new quality control tests for both physicists and radiographers. Because the major strength of digital detectors is their wide dynamic range, the optimisation process differs from screen-film because the correct exposure is no longer limited purely by contrast, but also by noise. Digital imaging is susceptible to a phenomenon known as dose creep but fortunately, this does not appear to have been an issue in digital mammography, thanks to the rapid development and adoption of new quality control tests, including a measurement of the parameter Signal Difference to Noise Ratio (SDNR) to achieve the optimum balance between dose and image quality [12].

In 2010, the ACPSEM ran the first Mammography Training Certification course and I was honoured to be asked to teach. Nine courses have now been run in total and I have taught on every one. I will retire after my 10th course! 59 physicists have successfully passed the course to achieve certification in CR mammography, DR mammography, or both. The process is rigorous, involving a pre-course assignment on the physics of mammography, 8 h of face-to-face training and 2 post-course assignments to demonstrate that the physicist is able to test a variety of equipment independently. In my view, quality control testing in mammography cannot be done satisfactorily without an understanding of the theory underpinning the tests. It is time-consuming and requires non-trivial image analysis and dosimetry. Occasionally there are trouble-shooting opportunities and it is possible for the equipment assessor to carry out remedial action, which avoids the need for a service visit. For these reasons, I find it stimulating and rewarding. It's great to interact with the clinical staff too, who show a real dedication to the field. There is usually a radiologist who is keen to get your opinion on a "flat" image (I think this means a lack of contrast, but I've never been sure!) or a diligent radiographer querying whether they should be concerned by a slight drift in their daily QC results (I think that some of them secretly enjoy QC!).

Radiographer QC is an area in which the mammography physicist should also play a key role. At the very least, they should review the QC log during their annual visit. In some respects, radiographers have faced more challenges than physicists, simply due to the number of routine QC standards that exist within Australia. Differences between national guidelines, local guidelines, vendor recommendations and the availability of medical physics support inevitably results in inconsistencies in testing methodologies between sites and a variation in the confidence level of radiographers in performing QC tests, interpreting results and taking appropriate action. Radiographers were faced with tests, tolerance levels and numerous acronyms which were initially unfamiliar to them. For example, measuring optical

density on a film was replaced with measuring mean pixel value (MPV) in a region of interest (ROI) drawn on the unprocessed image. Instead of aiming for an optical density of 1.7 OD, regardless of the X-ray system or screen-film combination, most tests now require monitoring the percentage deviation from a baseline MPV. The baseline will be completely different for every equipment vendor so the primary aim of routine QC is to ensure consistency in performance. Equipment performance will, of course, have been confirmed to be optimised during the medical physics acceptance test! Another aim is to detect and remove artefacts, before they become clinically significant. This presented yet another challenge; the cause, appearance and removal of artefacts in digital mammography is quite different to those from screen-film mammography.

Once again, RANZCR [13] and ACPSEM [14] must be acknowledged for the swift development of routine QC guidelines for digital mammography. Furthermore, ACPSEM, with funding from the Australian Department of Health developed an online, interactive training program for radiographers working in digital mammography which aimed to provide a nationally consistent approach to QC training and processes. The program is known as oMamQA (online mammography QA) [15]. It was published in April 2013 and has been endorsed by the Australian and New Zealand Institutes of Radiographers for CPD points. As of June 2015, there had been 363 enrolments.

Advances in technology

When people ask what I do, I will tell them that I am a medical physicist and surprisingly, many now seem to know what this is (or are too polite to tell me otherwise!). Once upon a time this was not the case, so I simply said I work for BreastScreen. Unfortunately, this answer was sometimes met with a frosty response. It obviously triggered a memory of a mammogram and one aspect in particular: breast compression. I often heard the comment "the equipment must have been designed by a man!" Well, yes, in fact it was; the first dedicated mammography unit was designed by French radiologist Charles Gros in 1965 [16].

So what has changed since then? From a quick glance at a modern mammography unit, the answer would appear to be very little. Equipment design remains much the same today and unfortunately compression is still a vital part of the exam. Of course, a key difference is the image receptor. Within Australia, screen-film has now been completely replaced with digital mammography. The next question is whether a *change* in image receptor technology represents an *advance*. From a purely practical perspective, the answer would have to be yes. There are numerous advantages associated with electronic images, including immediate viewing, post-processing and simplified transmission and archiving. However, in terms of improvements in clinical performance the answer is less straightforward, as it would appear that not all digital image receptors are created equal. The initial research goal was simply to determine if digital mammography was a suitable replacement for screen-film and the common (though somewhat underwhelming) conclusion was that the overall diagnostic accuracy of screen-film and digital mammography in the context of screening was comparable [17–20]. As digital mammography became more established, research focussed on the comparative performance of different digital detector technologies. The conclusions were unanimous; DR is the superior technology and offers a number of improvements compared to screen-film and CR.

Firstly, DR images can be acquired using a lower breast radiation dose (known as the Mean Glandular Dose, MGD) [21–24]. This is partially attributed to the use of harder beam qualities, with most digital systems now employing a heavily filtered tungsten spectrum. Secondly, sensitivity is improved in women with radiologically dense breasts [17, 25, 26], with one study quoting an increase from 55% for screen-film to 70% for digital mammography [17]. This is an important finding because breast density is a well-established independent risk factor for breast cancer, yet breast cancer is much harder to detect in women with high breast density (which includes younger women) because of the "masking effect". Mammography is a two-dimensional projection of the breast, hence superimposition is an issue and dense tissue can obscure structures of interest. Thirdly, DR has been shown to be significantly better at detecting high-risk lesions, which often manifest as calcifications [25–28]. This was perhaps an unexpected finding, given that the limiting spatial resolution of DR (5–10 lp/mm) is much lower than that of screen-film (15–20 lp/mm).

Unfortunately, CR has not offered such improvements [29]. Comparisons of cancer detection rates have either shown that CR is comparable to screen-film overall [30, 31], or comparable for invasive cancer only [26], or, worryingly, inferior to screen-film [32]. The difference in results between these studies is, in my view, attributed to differences in the CR performance of different vendors. A review of the UK NHSBSP technical evaluation reports indicates far more variation between CR systems than DR systems [24]. Even if clinical outcomes are comparable, the MGD required to achieve adequate image quality is higher than screen-film for all but one CR vendor [24]. Furthermore, my own testing experience indicates that the sensitivity of CR plates degrades over time and for CR systems greater than 3 years old, the MGD necessary to meet SDNR and image quality requirements is about 20% higher than that for a new system. In 2012, the ACPSEM therefore recommended that *only DR technology should be approved for*

future purchases of equipment for screening mammography in Australia and New Zealand and existing CR systems should be progressively replaced [14].

Further advancements in technology include Digital Breast Tomosynthesis (DBT) and Contrast Enhanced Digital Mammography (CEDM), both of which require only slight modifications to modern digital mammography apparatus. DBT involves the acquisition of a number of low-dose projection images in an arc around the compressed breast. The projection images are reconstructed into slices through the breast and DBT is often referred to as 3D mammography (although strictly speaking, the term *quasi-3D* should be used since the angular range is 15°–50°). The main advantage of DBT is that it significantly reduces the effects of superimposition, thereby enabling visualisation of lesions that would be masked by over- or under-lying tissue and distinguishing real lesions from those mimicked by superimposition of normal structures [29]. A number of studies on large screening populations showed an increase in overall cancer detection rate and a reduction in recall rate when using DBT in addition to 2D digital mammography, compared to using 2D digital mammography alone [33–36]. As expected, the greatest gains in sensitivity were observed for younger women and those with heterogeneously dense breasts [36, 37], but interestingly, there was no significant increase in cancer detection in those with extremely dense breasts [37]. DBT is currently being used in Australia as a diagnostic tool, but there is increasing evidence to suggest that it may be beneficial as a screening tool [33–36]. However, it is common practice to use DBT in conjunction with, rather than instead of, digital mammography, which results in a total examination dose approximately 2–3 times that of digital mammography alone. Interestingly, the relative increase is dependent upon breast glandularity, and has been measured to be greatest for fatty breasts [38, 39]. One DBT system has actually been shown to deliver lower doses to dense breasts than digital mammography [39]. In order to reduce examination dose, it is possible on some systems to synthesise a 2D image from the DBT data, rather than acquiring it, but the use of such an image in lieu of a digital mammography image is subject to further investigations.

CEDM employs a dual energy X-ray technique and requires the injection of iodinated contrast agent. With the breast under compression, two images are acquired in quick succession using energies above and below the K-absorption edge of iodine (33.2 keV). Subtracted images show suppression of glandular tissue and enhancement of contrast uptake, based on the principle of tumour angiogenesis, enabling improved detection and characterisation of breast carcinoma [40]. CEDM has demonstrated better sensitivity and specificity than digital mammography, particularly in dense breasts [41, 42]. Compared to MRI, CEDM is faster, cheaper, shares the appearance of digital mammography and offers equivalent sensitivity and improved specificity [43]. CEDM is currently being used as an assessment tool, and it is likely that this will remain the case, due to the requirement for contrast agent, which may be contraindicated in some women. CEDM alone has a similar radiation dose to digital mammography, but as with DBT, the technique is used in conjunction with 2D digital mammography. However, it has been shown that the low-energy mammogram obtained during CEDM may be a suitable alternative to the digital mammography projection image in the context of the assessment clinic [41, 42].

Both DBT and CEDM are now in use within Australia and are sufficiently different to 2D digital mammography to warrant additional QC tests. Furthermore, both employ different beam qualities to digital mammography, particularly high energy CEDM, with images being acquired at 40–49 kVp using a spectrum which is heavily filtered by copper or aluminium. This necessitates new dosimetry models. New QC tests for DBT have been developed [44], based on international guidelines and local experience and will be published in early 2017. The certification process for digital mammography aims to produce physicists with a good understanding of mammography physics and equipment functionality, such that they will able to perform these tests and interpret results without additional formal training.

The role of the medical physicist

In summary, the mammography physicist should not only be an equipment assessor, but someone who understands the technology enough to act as a trouble-shooter and advisor. As a relatively large group of specialized professionals, we have the resources to continually collect data and review results to ensure that equipment is not just satisfactory, but optimal; one example of this is the establishment of Diagnostic Reference Levels [45–47]. Throughout my career, it has been a privilege to work as part of a multidisciplinary team of dedicated mammography professionals, particularly radiographers and radiologists, who value the knowledge that a physicist brings to the field.

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