Advances in X-Ray Imaging

This article summarizes the proceedings of the recent symposium sponsored by Bracco Imaging at ECR 2018 on X-Ray imaging. Chaired by Prof. M Prokop, the symposium featured presentations by three experienced clinicians describing respectively the current status and future prospects in mammography; the key principles in improving the use of iodinated contrast media in modern CT systems and the optimal management of patient safety and economic aspects in a modern CT unit.

X-ray Mammography: today and tomorrow

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Prof Helbich began his presentation by showing several mammography images in which the high level of extremely dense fibroglandular tissue makes identification of cancerous lesions very difficult. This highlights one of the major challenges of conventional mammography, particularly for screening purposes. Having set the scene for his presentation, Prof Helbich then briefly described some of the recent technological innovations developed to meet this challenge and which are dramatically improving breast imaging practices.

Tomosynthesis

Although first described in 1998, tomosynthesis only entered routine practice much later, with the advent of digital mammography. Now, digital breast tomosynthesis (DBT) is a well-established, powerful technique, in which "sliced" images of the breast enables identification of lesions that would otherwise be missed at conventional mammography [Figure1]. Although a drawback of DBT when used together with conventional mammography is an increased radiation dose, this can be overcome by using synthetic reconstructions of a two-dimensional mammogram from the reconstructed tomosynthesis slices, thereby avoiding the need for a separate conventional digital mammogram. The combination of tomosynthesis plus synthetic 2D mammography allows lower overall radiation dose, shorter compression time and superior performance in terms of lesion detection. Advantages of DBT include improved cancer detection, increased accuracy and reduced patient recall rate. This has led to the question as to whether DBT could replace conventional mammography in screening applications. Several studies, using systems from several vendors and involving large numbers of women, have shown that the use of DBT allows a significant increase (between 27% to 54%) in cancer detection rate. A consequence of these findings has been an explosion in the numbers of sales of tomosynthesis systems.

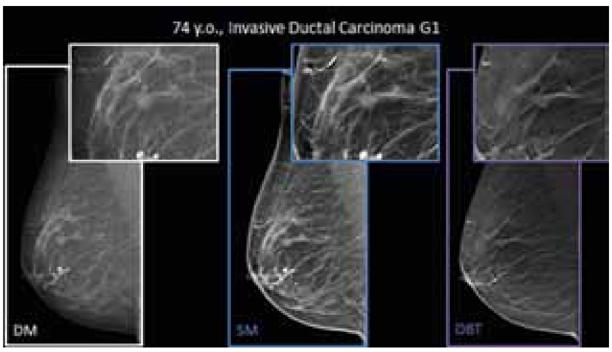

Figure 1. Digital Breast Tomosynthesis is increasingly replacing 2D Mammography principally because DBT can detect significantly more cancerous lesions than 2D MG, Left Panels: DM, digital mammography. Central Panels: SM,synthetic 2 D mammogram. Right Panels: DBT, digital breast tomosynthesis.

Contrast enhanced dual energy mammography (CEDEM).

Contrast-enhanced MRI is the imaging modality with the highest sensitivity for breast cancer detection. Studies using "abbreviated" contrast enhanced MRI screening protocols have shown that this approach results in a cancer detection rate of 18/1000 women screened (compared to 7 - 9/1000 with DBT and 3 - 4 /1000 for mammography). The question is whether similar benefits are attainable in mammography with the use of appropriate iodinated contrast media. Such contrast enhancement is already established for standard non-breast CT examinations.

In practice, CEDEM involves modification of the X-ray spectrum of a standard mammography system through the use of filters and modified software. The procedure involves the acquisition of a low energy image as in normal mammography, followed by a high energy image and subtraction of the two images, with the final subtracted image revealing cancer lesions that have taken up contrast [Figure 2]. For a successful CEDEM examination, appropriate contrast agents and an efficient contrast injector are essential. A review of the literature shows that contrast injection flow rates of 3-5 mL/sec are used in CEDEM, at 1-1.5 mL/Kg body weight. While a range of iodine contrast concentrations have been used, higher iodine concentrations (e.g. 400 mg/mL) are advantageous in increasing lesion conspicuity and facilitating reductions in radiation dose. In short, CEDEM has proven feasible and easy to perform, with a cancer detection rate similar to that of MRI across all densities of breast tissue.

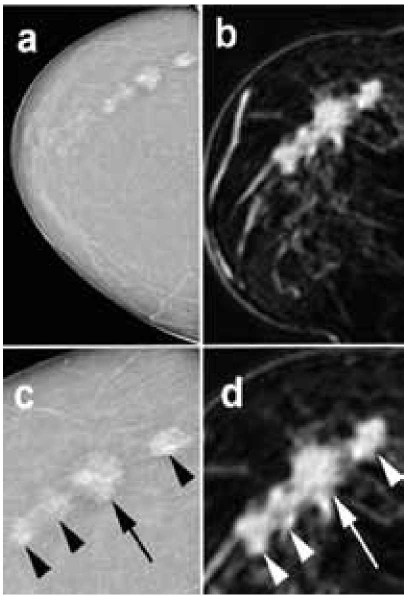

Figure 2. The sensitivity of Contrast-Enhanced Dual Energy Mammography (CEDEM) has been shown to be equivalent to that of breast MRI.
Images a & c: CEDEM; images b & d: MRI.

Contrast enhanced tomosynthesis (CE tomo)

The above two innovations in mammography, namely DBT and CEDEM have each been shown to have their own advantages, so a logical follow-up is to evaluate whether they can be combined into one combined imaging modality, CE-tomo. Initial studies on a prototype system suggest that the performance characteristics of CE – tomo are similar to those of MRI.

Contrast enhanced CT (CECT)

Other workers consider that contrast-enhanced tomosynthesis is just one step on the way to the ultimate goal which would be contrast- enhanced CT in which images are taken right around the breast, instead of a limited number of slice images as in DBT. Two CECT breast systems have been developed so far, one of which uses a photon counting detector and has been shown to detect not just masses but also microcalcifications with high sensitivity. Yet another very recent innovation is gating-based phase contrast CT .

Conclusion.

With the possible exception of screening in high-risk women where MRI still remains the optimal modality, the recently developed technologies of CE mammography, CE tomo or even CE CT have the potential to cover all applications in the field of breast imaging.

How to improve the use of iodinated contrast media in modern CT systems: key principles

Prof Luis Marti-Bonmati

Prof Bonmati reminded the audience of the basic rationale for the use of contrast media in CT, namely to improve the intrinsically poor soft tissue contrast of CT, to give improved conspicuity of any pathological soft tissue alterations. The most important parameters that should be considered when selecting a protocol are the iodine delivery rate (IDR) and the total iodine dose. [Figure 3].

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Iodine delivery rate is the amount of Iodine in g/sec that is administered to the patient. An appropriate IDR is particularly important for vascular (CTA) and perfusion examinations involving the first pass of iodine through the scanning window. The total iodine dose, on the other hand, is of greater importance for organ or tissue parenchymal studies in which a higher total iodine dose results in greater enhancement thereby improving the accuracy for cancer detection and characterization.

Of course these contrast media aspects have to be considered together with factors relating to the CT scanner itself, e.g. tube voltage (kV) and current (mA), scan duration, scan delay, type of scan, etc., as well as those relating to the patient, such as the organ being examined, the patient's age, weight, cardiovascular status, renal function etc. The radiologist's responsibility is to manage protocols to optimize the various scanner and injection parameters for each individual patient.

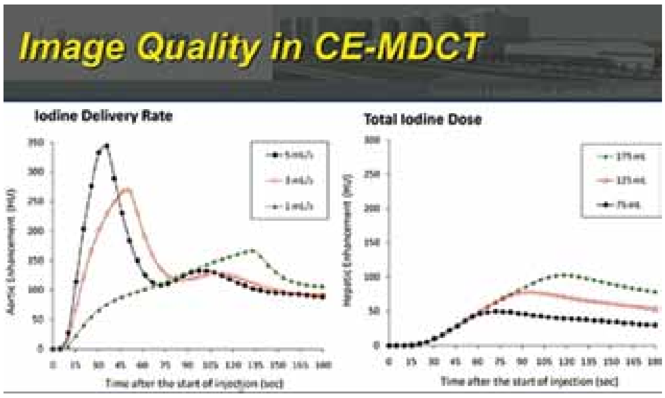

Figure 3. The most important parameters that should be considered when selecting a protocol are the iodine delivery rate and the total iodine dose. Images reproduced from *Bae KT. Intravenous contrast medium administration and scan timing at CT: considerations and approaches. Radiology. 2010; 256: 32-61.*

Prof Bonmati thereafter focused on the benefit of high concentration contrast media (**HCCM**) in CE CT

Radiation exposure. Nowadays a major focus is on reducing the radiation exposure in CT examinations. HCCM (e.g. CM containing 400 mg Iodine/mL) have the potential to permit reductions of radiation beyond those routinely attainable using automated dose modulation systems. Such approaches are in keeping with the ALARA principle which aims to reduce radiation exposure to a minimum.

Reducing radiation dose with HCCM. The higher iodine content in HCCM gives an increased signal for a given injection rate. This means that more noise can be accepted during image acquisition for a given contant signal to noise ratio (SNR). This in turn means that the tube current (mA), which is directly proportional to radiation dose, can be reduced while maintaining identical SNR. This reduction in radiation dose can be as much as 40% if a 400 mg/mL concentration of contrast is used instead of 300 mg/mL. In addition, lesion conspicuity is increased due to the tighter bolus during contrast injection

Arterial enhancement in CE-CT. Early and late phase enhancement, i.e. arterial and capillary phases, respectively, is affected by the iodine delivery rate (IDR). Thus, for the same concentration of contrast agent, the higher the speed of administration the higher (and earlier) the peak of arterial enhancement. Conversely, a higher volume of CM would lead to a higher (and later) peak enhancement. Use of a lower concentration CM would necessitate administration of a higher volume at a faster injection rate to match that achievable with HCCM. This may not always be feasible or desirable, for example in the case of young pediatric patients or older more frail patients with poor venous access.

A higher IDR produces a sharper bolus which results in a higher peak enhancement and a lower waste of contrast media with fast scanners. The use of a saline flush increases the arterial enhancement and the time to peak. In general use of HCCM at a relatively fast injection rate is optimal for improving first pass image quality at low radiation dose.

Parenchymal enhancement. The degree of parenchymal enhancement reflects the Total Iodine Dose (TID) administered and is independent of the IDR. Parenchymal enhancement is inversely proportional to body weight and is improved with a saline flush. A total iodine dose of 600 mg iodine/kG body weight is usually adequate. However a better result can be achieved if the lean body weight (LBW) can be measured, in which case a TID of 800 mg/kG LBW is routinely used. Using HCCM, this means the TID can be achieved with 2 mL of 400 mg/mL HCCM

Timing. Patient factors need to be taken into account when estimating the time necessary for the CM to reach the tissues being imaged. Thus, a fixed delay between contrast injection and the start of scanning is not optimal because of patient variability. A test bolus is time-consuming so bolus tracking is the preferred method. In bolus tracking, a trigger threshold (typically 100 Hounsfield Units) is fixed, after which typical delays are set, e.g. 6 sec for the early arterial phase, 12 sec for the late arterial phase, 48 sec for the portal phase and even 180 second for the interstitial delayed phase.

HCCM summary

• High concentration contrast media gives a higher signal. For a constant SNR, more noise can be accepted so radiation dose (mAs) can be reduced : " High iodine concentration — low mAs"

• The constant SNR approach can be further optimized through the use of iterative reconstruction,

• Heating the Contrast Media to 30 -35° C decreases its viscosity and peak pressure. Together with smaller volumes, such heating reduces adverse events and facilitates contrast distribution

• In both early and late arterial phases a high IDR (2gI/s at high concentration, fast injection rate with a sharper bolus) yields a higher signal

• Enhancement of arterial and hypervascular lesions (early and late phases) depends on the IDR (1.5gI/s) and the injection duration which should be as short as possible (4mL/s) — shorter and faster bolus.

• Parenchymal enhancement, is proportional to TID. The volume should be adjusted in accordance with the LBW to reduce inter-patient variability.

• Monophasic protocols give more consistent enhancements.

A typical abdominal protocol in routine use at La Fe Hospital is shown in Figure 4.

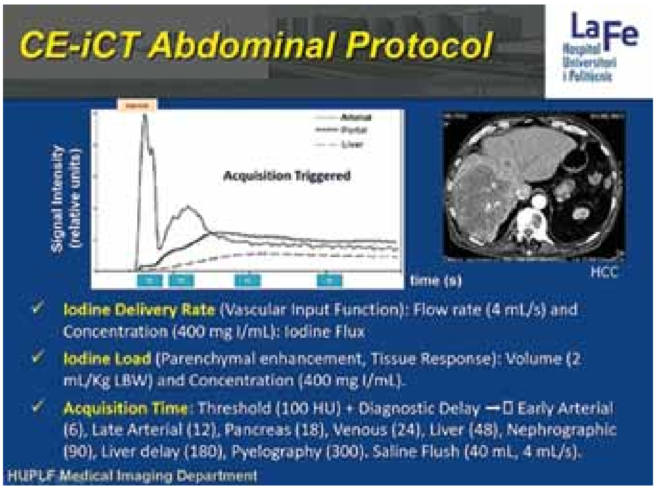

Figure 4. A typical abdominal protocol in use at La Fe Hospital, Valencia

How to best manage safety compliance and economics in a modern CT unit.

Prof Mathias Prokop

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There are many factors which have to be taken into account for optimal management of a modern CT unit but they can be classified into two main categories. The first covers quality, safety and compliance aspects, which include :

• Individual optimization of contrast and radiation dose;
• Traceability of contrast and radiation dose delivery
• Compliance with DRLs
• Protocol management

The other main category deals with economic aspects and covers subjects such as:

• Ensuring high scan throughput;
• Minimising waste of contrast media;
• Ensuring that the cost of disposables is acceptable.

A key component which helps to attain these objectives is the use of high concentration contrast media **HCCM** (e.g. Bracco's HCCM provides 400 mg I/mL), which not only gives high enhancement when required, but can also be utilized to reduce radiation dose (of special importance in young patients).

Individualization of radiation dose.

For this, xyz tube current modulation is now current practice in modern scanners where the tube current is modulated to local x-ray attenuation, to give a more homogeneous detector signal and ultimately provide similar image quality, independent of the body region. Closely connected with xyz modulation, automated exposure control (AEC) is now also standard on modern CT systems and adjusts the tube current to the global x-ray attenuation, so that similar image quality is produced, independently of patient size.

Individualization of contrast dose.

For this, the injection time is kept constant, but the contrast volume and flow rate are varied as a function of the size of the patient, The overall effect is that similar enhancement can

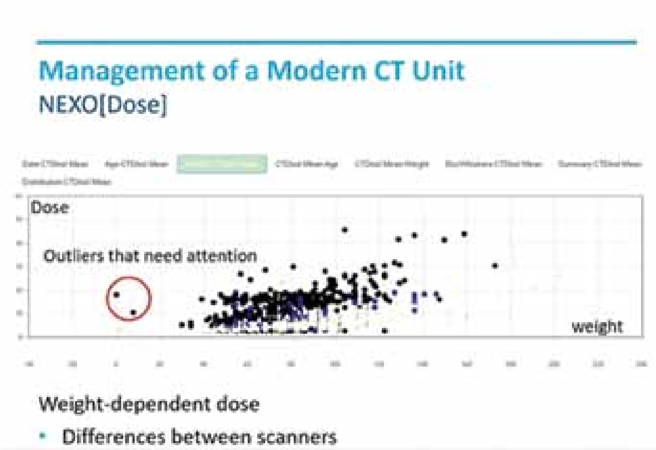

Figure 5. Example of group data presented by Bracco's NEXO [Dose] system

be achieved for all patients, with smaller patients receiving less contrast and better enhancement being achieved in larger patients.

High contrast concentration

In Nijmegen, high contrast concentrations (Iomeron 400) are used to maximise Contrast to Noise Ratio (CNR) for CTA in young individuals, for cardiac CT and for perfusion imaging, where the contrast media is pre-warmed to 38 ° C to reduce viscosity.

Interaction between individualized radiation and contrast dose

It is well established that for a constant iodine concentration the use of lower kV provides more enhancement. There is an inverse square relationship between noise and radiation dose, so to reduce noise by a factor of two, i.e. increase the CNR by a factor of two, the dose would have to be increased by a factor of four. On the other hand, a two-fold increase in CNR can also be achieved by increasing the amount of contrast by a factor of two. Thus increasing the contrast can be a powerful adjunct to mA reduction alone.

Where low radiation exposure protocols are indicated, e.g. for CTA, cardiac patients, slim patients or children, the selected parameters should be high contrast concentration, high flow, low kV (but a wide window setting is required). Iterative reconstruction should always be used. Such protocols are particularly suitable for young patients, who frequently have a high cardiac output, especially when they are nervous. Their renal function is generally good so total iodine dose is usually not a limiting factor and they are generally not obese, so low kV settings are more often possible. With young patients, the radiation risk is higher so it is important that the radiation exposure be

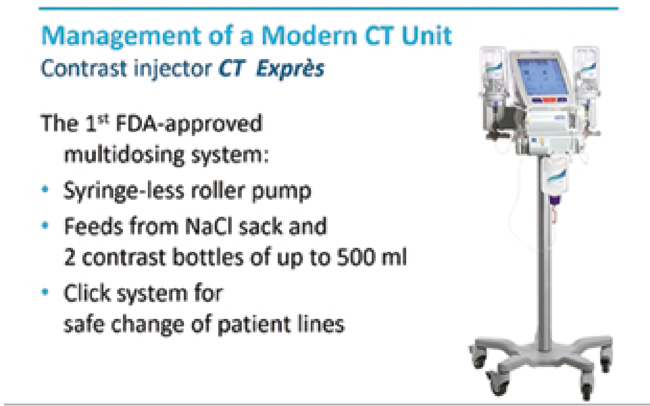

Figure 6. Bracco's CT Exprès contrast injector

reduced.

However if low contrast volume protocols are required, e.g. for renal failure or elderly patients, the parameters should be low volume, low flow, low kV with normal window setting and iterative reconstruction.

Monitoring software.

An integral contrast/ dose management tool is highly useful for tasks such as centralizing protocol management; giving safe web access; uploading data to HIS/ RIS/PACS; monitoring protocol use and compliance and for creating performance reports.

Bracco's NEXO [Dose] system carries out all these functions. An advantage of the system is that data can be presented from groups of patients. For example, Figure 5 shows a scatterplot of radiation dose as a function of patient body weight, from which it can be seen that there are a couple of outliers, namely two low body-weight patients who received too large a radiation dose.

Likewise the performance of different scanners can be examined through use of aggregated data. However it is not just group data that are presented; it is possible to evaluate individual patients/ protocols. The system also detects any suboptimal protocol design, errors in AEC settings or operator errors.

Contrast injection

Ideally, contrast dose should be personalized on the basis of standardized protocols in order to ensure safety of the administration procedures, to comply with best practices and guidelines as well as to minimize contrast wastage. In practice this is not so easy. For example there are differences in regulations between various European countries. In addition, often contrast medium is supplied in fixed bottle sizes so that a considerable amount of contrast may be unnecessarily discarded — home-made solutions to overcome this run the risk of sterility problems, backflow of blood etc.

Bracco's CT Exprès contrast injector solves such problems [Figure 6].Approved by the FDA, the multidosing system is syringe-less and feeds from an NaCl bag and from two contrast bottles of up to 500 mL. A click system allows safe exchange of patient lines.

In Nijmegen this system has now been adapted in routine use and has been found to be very flexible, with enough contrast from one bottle for 8 – 12 patients and with pre-warming of the contrast media to 38 °C. Patients can be changed rapidly and the contrast bottle can be changed at leisure. The system is safe with no backflow, air detection and is clean, with no leaks.

Take-home messages for optimal management

Safety and compliance.

- Individualized contrast and radiation dose Less radiation/ more contrast in young patients More radiation, less contrast in patients with renal impairment
- Protocol management
- Monitoring software for compliance, dose reporting and performance bench-marking

Economics

- High throughput injector allows more patients per day with minimal waste of contrast
- The correct amount of contrast is always injected