Patient Specific Dose in Chest X-Ray Imaging Modalities

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Researchers look at the effect of patient body size on dose metrics from chest radiography, tomosynthesis, and CT scans.

Patient receiving a CT scan (Image taken from Wikimedia Commons)

Researchers at Duke University estimated the organ doses, effective doses, and risk indices for different sized adult patients undergoing clinical x-ray chest imaging. The modalities that were investigated were chest radiography, tomosynthesis, and x-ray computed tomography (CT). Computational phantoms of varying body types were used in a Monte Carlo simulation to estimate these dose metrics. The results, which were published this month in the *International Journal of Medical Physics Research and Practice*[1], showed that patient size has a much greater effect on the radiation dose obtained from a chest CT scan when compared to the doses obtained by chest radiography or tomosynthesis.

Radiation dose is inherent to any x–ray modality. However, the ALARA (As Low As Reasonably Achievable) principle is always used when choosing which imaging modality is best for a particular patient in terms of minimizing their dose while still obtaining suitable image quality for diagnosis. But in order to implement the ALARA principle, the organ doses, effective doses, and risk indices for each of the modalities need to be accurately known. While there have been other studies comparing radiation dose in these three chest x-ray modalities, these studies only used one generic phantom. According to the researchers at Duke, to the best of their knowledge this is the first study comparing dose across these modalities using a wide range of patient sizes.

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[1] *Comparison* of *patient specific dose metrics between chest radiography*, *tomosynthesis*, and *CT* for *adult patients* of *wide ranging body habitus*
Yakun Zhang, Xiang Li, W. Paul Segars and Ehsan Samei
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Whenever x-rays, or any other ionizing radiation for that matter, penetrate a person's body, they deposit energy, which can damage tissues in the body. This energy that is deposited is what is known as dose[2]. Different organs in the human body have different sensitivities to ionizing radiation. Effective dose is a metric that measures the effect of a particular radiation exposure on overall health. Effective dose is calculated by multiplying each organ dose by a weight factor, which takes into account that organ's radio-sensitivity, and then summing the result. However, a better dose metric for indicating the overall effect of ionizing radiation for a particular patient, is a risk index. The risk index that was used in this study was developed at Duke University, and takes into account the patient's gender and age along with the effective dose that they are receiving.

In this study, computational phantoms were created based on previous patient scans in the Duke CT database. The scans that were chosen to create the different computational phantoms were of adult male and female patients, and represented a wide range of body types and ages. These computational phantoms were then used in a Monte Carlo simulation called PENELOPE, which simulated imaging using each of the three modalities and then calculated the organ doses from each modality for the different phantoms. The effective dose and risk index for each phantom were calculated based on the organ doses given by the Monte Carlo simulation. The results of these simulations showed that as the average chest diameter of a patient increased, the effective dose and risk index for CT scans increased exponentially. However, for chest radiography and tomosynthesis, the effective dose and risk index only increased slightly with an increase in the average chest diameter of a patient.

While talking with Yakun Zhang, one of the researchers at Duke involved in this study, she indicated that the next steps in this research could be extending this work to pediatric patients, or looking at the image quality of these modalities along with the dose for different sized patients. When it comes to looking at the image quality along with the dose, the whole idea is to maximize a patient's benefit to risk ratio. If a patient is getting a small dose from an imaging exam but the image quality is poor, than in terms of their benefit to risk ratio it is not really worth it. As Yakun told me "…dose is really only half of the story; you need to take image quality into account as well when determining the best imaging modality for a particular patient".

[2] From CNSC website: http://www.cnsc-ccsn.gc.ca/eng/readingroom/radiation/radiation_doses.cfm

Interview with Yakun Zhang
January 23, 2014

1. **Is patient size currently used in practice, to determine what the best imaging modality is best for a particular patient?**

   Yes and no. It is different for different medical centers, but here at Duke we do take patient size into account, especially for CT imaging. The protocols that we have in place at Duke for adult patients, categorized them as regular or obese. When dealing with pediatric patients however, we look at patient size more closely when determining the best imaging modality. For pediatric patients we have different protocols with a wider range of size classifications than those for adults.

2. **Why exactly does patient size have a much stronger affect in CT scans when it comes to effective dose?**

   For CT scans several measurements are taken from different positions around the patient. So the patient is getting more x-rays penetrating their body. According to the Beer-Lambert Law, as the thickness of an object increases, the dose increases exponentially. So if we compare say a patient with a 20cm diameter chest and one with a 30cm diameter chest, for regular x-ray imaging that would be a difference of 10cm. However for CT, several measurements are taken so this could end up being up to a 200cm difference.

3. **Why does dose to internal organs, such as lungs and liver, tend to increase with chest diameter? To me it seems that these would decrease as there would be more tissue shielding these organs.**

   You're absolutely right that larger patients have more shielding, but because there is more shielding, we need more x-rays and need to increase the kVp to get an image with similar image quality to a smaller patient. So even though there is more shielding, the organs still pick up a higher dose because more x-rays at higher energies are used.

4. **In your section on Limitations and Future Work, you stated that the protocols used in this study correspond to clinical operation. Is there much variation in imaging parameters (such as kVp) for the clinical applications of these imaging modalities?**

   The imaging parameters for chest imaging are pretty standard. For chest imaging we usually use 120 kVp, which I used in the paper. However, for larger patients, 140 kVp is normally what is used.

5. **How do hospitals monitor the dose that patients are receiving from these x-ray modalities?**

It has only been over the past few years that medical centers, at least in the United States, have started tracking patient dose. Most of the dose tracking has been for CT scans. Now for every CT scan, the dose that the patient received is required to be outlined in a report. At Duke, we have in house software that tracks dose for every modality. What we do with this data is look at the trends and see if there are any outliers which could indicate if there were any issues with the equipment or the technician running the test. In general though, dose tracking is beginning to move towards all modalities. Dose tracking is a very hot topic!

6. What do you mean when you say "Effective dose however, is not explicitly defined for an individual patient"?

The term "effective dose" started in ICRP (International Commission on Radiological Protection) Publication 26. It is calculated as a sum of the organ doses multiplied by an appropriate weight factor. It was developed based on a reference phantom, and the weight factors take into account which organs are more radiosensitive than others. At Duke we have developed a risk index that we look at in addition to effective dose. The risk index gives us a clearer picture than effective dose of the risk to an individual patient, as the risk index takes into account the patient's gender and age.

7. Are there any plans at this time for you to build upon this research, such as looking at image quality along with dose for different sized patients or looking at this work applied to pediatric patients?

I will not be continuing this research as I am graduating. However, if I did continue this research I would definitely go in this direction. I would especially focus on the role that image quality plays, because dose is really only half of the story, you need to take image quality into account as well when determining the best imaging modality for a particular patient.