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Dyanmic x-ray beam positioning for low-dose CT  
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## Paper Critical Review

### **Paper Selection**

*Toth, T., Ge, Z. and Daly, M. P. (2007), The influence of patient centering on CT dose and image noise. Med. Phys., 34: 3093–3101. doi:10.1118/1.2748113*

The paper chosen for this seminar by Toth et. al. describes a study into the clinical impacts of patient mis-centering in clinical CT imaging scenarios. Specifically, the authors of this study analyzed dose and image noise – a metric of image quality – for phantoms positioned off-center in a GE Lightspeed VCT scanner, and used this data to develop tools to predict dose and noise penalties in clinical data. Because dose and image noise are fundamental concepts in CT, this paper is of great interest to the medical physics community as a whole. For our team specifically, this paper presents an approach for studying the clinical consequences of mis-centering and confers a crucial clinical context for our problem’s need statement.

### **Paper Background**

Toth begins his paper by motivating the need for studying dose and image quality in CT. He explains that while good image quality is necessary to accomplish medical diagnosis, better image quality comes at the cost of increasing the x-ray dose to the patient. In fact, the image noise is inversely proportional to the square root of the dose, meaning that to halve the image noise, the dose to the patient needs to be quadrupled. He then proceeds to mention that existing scanners use a technique called automatic exposure control to promote constant image quality, before proceeding to talk about beam filters, which are used to modify the spatial profile of the beam in a way that will reduce the dose without negatively impacting the image quality in a substantially negative way. He points out previous studies that have shown the importance of matching the right size and shape of bowtie filters to the object, but indicates that these studies all assume a centered bowtie. Toth says that effect of patient mis-centering when imaging with a bowtie is poorly understood, and motivates the paper by saying he will develop methods to quantify mis-centering in clinical imaging scenarios and assess the associated dose and image noise penalties.

### **Methods**

The first part of the methods section describes how the phantom dose and noise measurements were performed. Toth shows a table of the different phantoms that he uses, which have vary in material and effective diameter and include various water phantoms, CTDI phantoms and tissue equivalent phantoms. He will perform the study on a GE Lightspeed VCT, a clinical-grade CT scanner, with acquisition settings of 120 kV, 8x5mm axial collimation and 1s rotation period. He will take measurements for each of the phantoms positioned 0, 3cm, and 6cm below isocenter in the gantry, and for 3 bowtie filter sizes each: large, medium, and small. To estimate the mis-centering of the objects, he will take scout scans (or “SPR”) of the object at the AP and lateral views. Axial dose will be measured using 10cm pencil ionization chambers during the acquisition, and image noise will also be evaluated by looking at the standard deviation of values in difference images (of reconstructions), both of which are standard practice in research.

Toth then proceeds to describe the “novel” methods he has developed to study mis-centering. First, he describes an object size metric called sqrtPA, which is essentially the square root of the projection area, where the projection data is  $P$ . To find the amount of mis-centering, the centroid of the projection is calculated and subtracted from the detector channel corresponding to isocenter, as shown in Figure 1. Unfortunately, as Toth points out, in the lateral projection data the measurements will contain a contribution from the table. Hence, Toth develops a method to correct for the error introduced by the table by creating a regression model as a function of the sqrtPA of the projection, which may be reasonable because the relative contribution of the table to the projection data will vary depending on the size of the patient. To develop this regression model, Toth simply records the actual table value from the table readout values, and uses this data with the initial mis-centering estimate to find his regression model.

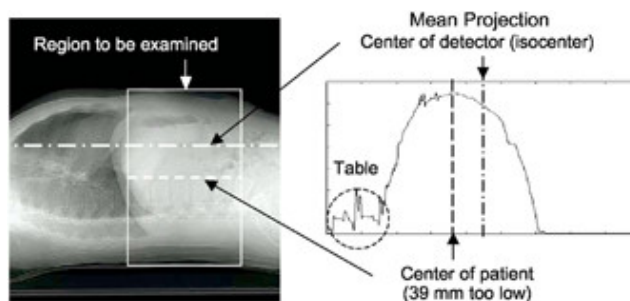


Figure 1: Centroid Calculation

Finally, to extend the analysis so that it can be capable of analyzing dose and noise penalties in clinical data, Toth describes the computer assisted parameter selection CAPS software developed in MATLAB. This software has incorporated the techniques described above to calculate sqrtPA, centroid, and the table regression model to estimate the mis-centering value. It additionally contains extra regression models to estimate the noise (specifically in the lower ROI) and dose increase (specifically in the anterior region in an axial slice) to the object as a function of the error-corrected mis-centering estimate and the sqrtPA. This regression model is computed from the data collected by scanning the different phantoms of different effective sizes that were described above. This overall pipeline will be used to analyze 549 AP and lateral SPRs collected from previously concluded clinical studies (hence, a completely retrospective analysis).

## Results & Discussion

In general, the mis-centering calculation was above to achieve sub-millimeter accuracy, as shown in the Table below:

	w12	w20	w25	w35	w46	P48
0	0.64	-0.33	0.46	-0.36	-1.17	0
-30	-0.14	-0.88	0.02	-0.53	-1.07	-3.78
-60	-1	-1.62	-0.43	-0.29	-7.98	-12.15

Table 1. Centroid calculation accuracy

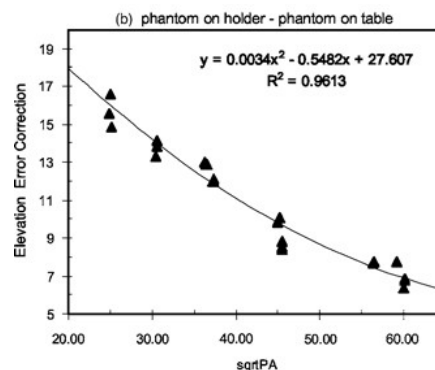


Figure 2: Table Error Model

The data shown above was obtained by scanning phantoms mounted in air, and were therefore not corrupted by contributions from the table. Hence, the data represents the accuracy of the centroid calculation technique by itself. In general, it seems to work well except with the large error in the w46 and P48 phantoms, where it is said that part of the object is outside of the FOV, which corrupted the calculations. The regression model that is used to determine the table error is shown in Figure 2, which plots simply the offset value to add to the centroid-based estimate. As shown, the errors are larger for smaller patients, which seems like a reasonable result.

The dose and image noise results for the phantoms are shown below in Figure 3. From the CTDI measurements, it is observed that for larger and larger centering errors below isocenter in the bore, the dose to CTDIA and CTDI0 is increased, whereas the dose to CTDI90 and CTDI180 is decreased. This is consistent with expectation, since lowering the object will over-expose the anterior part of the object and under-expose the posterior part for most of the 360 rotation in the scan. From the “heat maps” of noise shown on the right, it is evident that with increasing amounts of centering error, the largest amount of noise tends to shift towards the lower part of the image (where with no centering error the largest noise is shown to be in the middle, which is consistent with expectation). The figure also shows a plot of the average total, upper, and lower ROI noise, indicating that in general, while the upper ROI noise decreases only slightly as a function of the degree of centering error, the lower ROI noise increases much more dramatically. Combined with the information shown from the dose measurements, we see that even though approximately the same amount of extra dose given to the upper ROI is taken away from the lower ROI, the impacts on image noise are not the same. This figure overall serves to demonstrate the critical impact of mis-centering on image quality remarkably well.

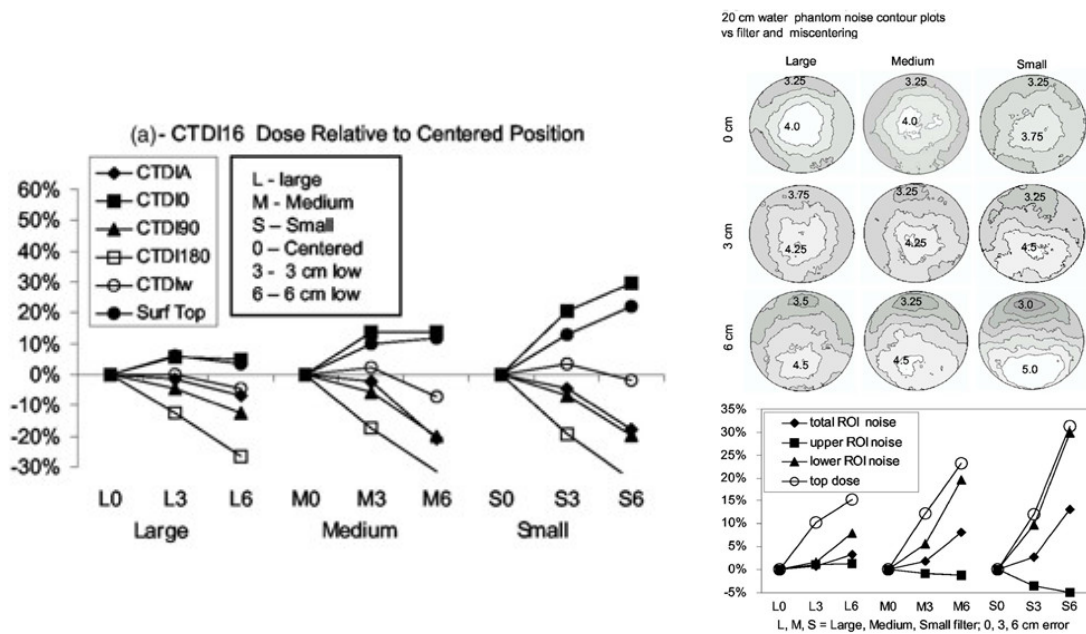


Figure 3: Dose and Noise Results for Phantom Measurements

Then, Toth shows plots of the top surface dose increase and lower ROI noise decrease as a function of 0, 3 and 6cm mis-centering for many different phantoms. This data is used to find the

final regression model that estimates the noise and dose impact from mis-centering and object size, though this regression model itself is not shown and only the  $R^2$  values are reported.

Finally, Toth proceeds to analyze his clinical data. The mis-centering errors determined from the clinical SPRs are shown below in Figure 4.

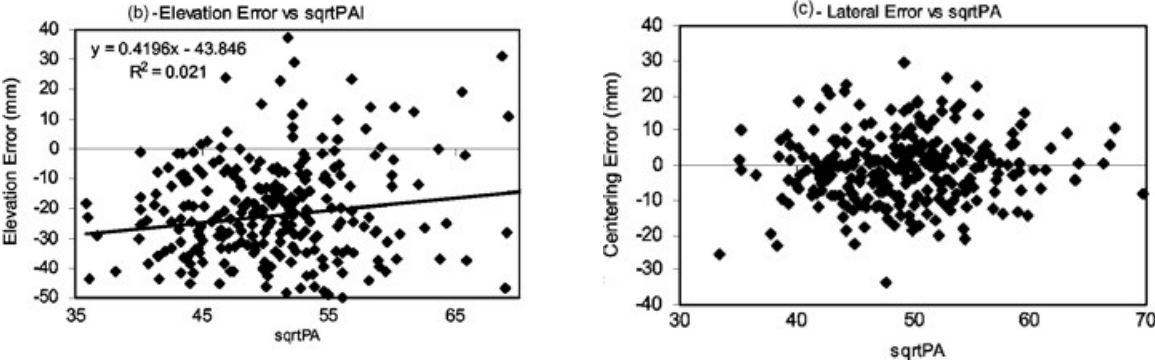


Figure 4: Clinical Mis-centering Errors

The left plot shows the elevation error, or the offset determined from the lateral view, and the right plot shows the lateral error, or the error determined from the AP scout. As might be inferred from the plot, the lateral error ranges from -2.9 to 3.3cm with a mean of 0.0 cm, whereas the elevation error ranges from -6.6 to 3.4 cm with a mean error of -2.3 cm, indicating a bias. In fact, it is observed that 74% of patients were mis-centered at least 1cm, and 22% were mis-centered at least 3cm. Finally, the small inclination in the regression shown in the figure suggests slightly that there may be a trend for smaller patients to be lowered more than large patients in the bore, which it is suggested may be to help patients mount and dismount. Finally, the dose and noise impacts of these mis-centering estimates is shown below in Figure 5.

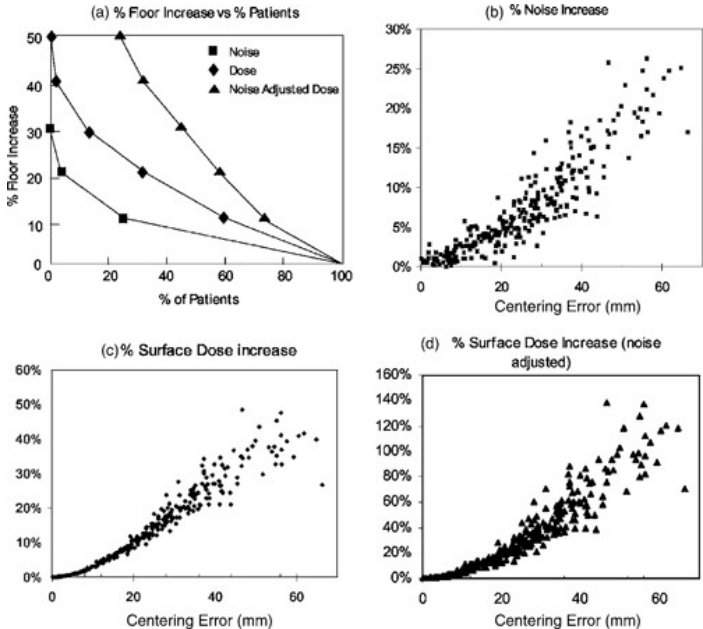


Figure 5: Clinical Dose and Noise Impacts

In the Figure 5a, a plot of the proportion of patients that experience at least a certain amount of increase in dose or noise from baseline is shown. Figure 5b-d shows plots of the dose or noise increase as a function of centering error. The data indicates that there is a mean noise increase of 7%, a mean surface dose increase of 15%, and a mean noise adjusted surface dose increase of 33%. Note that the noise adjusted surface dose estimate comes from assuming that the acquisition parameters are modified in order to offset the noise increase in the lower ROI, and may represent a realistic value in a clinical scenario where the mAs is simply increased to account for mis-centering. For 50% of patients, there was a minimum noise increase of 5%, a minimum surface dose increase of 15% and a minimum noise adjusted surface dose increase of 25%.

### **Assessment**

This paper represents an important paper that describes dose and noise impacts in clinical imaging scenarios for various degrees of mis-centering and does so using a clinical CT scanner. Importantly, this paper developed useful tools to assess patient size, mis-centering, and models for estimating dose or noise penalties solely from scout data, which allowed them to estimate impacts of mis-centering in clinical imaging scenarios. To my knowledge, this was the first paper to demonstrate that there is in fact a systematic tendency in the clinic to lower the patient within the bore and show that the dose and noise consequences are fairly substantial.

Unfortunately, extrapolating absorbed dose measurements in phantoms to dose in real patients is not as straightforward as the regression described in the paper. Specifically, the most important metric in real patients is effective dose, which requires a tissue-specific weighting factor. Hence, the clinical dose values reported in this paper may be an inaccurate representation of the increase in effective dose in real patients, although it still provides a useful baseline. The biggest fault I can identify in this paper is that the analysis appears to be too restrictive. Specifically, the authors seem to unnecessarily limit themselves to making analyzing only mis-centering below isocenter, even though the data shows that there is still a lot of mis-centering that occurs above isocenter. Though the trends may simply be the opposite of those observed in the data presented, it may have been useful to add an extra point on those plots representing the -1 or -2 mis-centering value, for example. Additionally, the authors developed dose and noise models only for abdominal imaging, as they used data collected from phantoms with sizes similar to the abdomen. Hence, the results in this paper may not be easily extrapolated to other imaging scenarios, such as head CT, which is what our project concerns.

### **Conclusion**

This paper provides an invaluable clinical context and background to the patient mis-centering problem. Importantly, this provides the literature support and helps motivate our need statement, that there are severe dose penalties to mis-centering and imaging without bowtie filters in the emergency department. In our project, we may also be able to use a similar analysis to the paper in order to study dose and noise impacts with and without the use of our system. Specifically, we can similarly study noise and dose increase as a function of centering error, and in addition show extra plots that correspond to measurements with and without the use of our automatic positioning system to demonstrate the differences. The data from the paper indicates the general trends we might expect from CTDI measurements, and taught us a potentially useful way for studying the spatial dependence of noise.