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Automated patient centering of computed tomography images and its implementation to evaluate clinical practices in three hospitals in Indonesia

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Abstract

Purpose: This study aims to develop a software tool for investigating patient centering profiles of axial CT images and to implement it to evaluate practices in three hospitals in Indonesia.

Methods: The evaluation of patient centering accuracy was conducted by comparing the center coordinate of the patient's image to the center coordinates of the axial CT image. This process was iterated for all slices to yield an average patient mis-centering in both the x- and y-axis. We implemented the software to evaluate the profile of centering on 268 patient images from the head, thorax, and abdomen examinations taken from three hospitals.

Results: We found that 82% of patients were mis-centered in the y-axis (i.e., placed more than 5 mm from the iso-center), with 49% of patients placed 10–35 mm from the iso-center. Most of the patients had a tendency to be placed below the iso-centers. In head examinations, patients were more precisely positioned than in the other examinations. We did not find any significant difference in mis-centering between males and females. We found that there was a slight difference between mis-centering in adult and pediatric patients.

Conclusion: Software for automated patient centering was successfully developed. Patients in three hospitals in Indonesia had a tendency to be placed under the iso-center of the gantry.

Keywords: iso-center; mis-centering; centering profile.

Introduction

The utilization of computed tomography (CT) as an imaging modality in pediatric and adult patients continues to increase[1,2], because of the wealth of information in the CT image supporting an accurate diagnosis.[3] However, the high dose in CT examinations is a constant concern.[4,5]

Many techniques to reduce the doses received by patients in CT examinations have been developed.[6,7] One of them is the utilization of tube current modulation (TCM). TCM makes it possible for practitioners to modulate tube currents based on the patient's specific size, shape, and anatomy.[8,9] With TCM, the reconstructed image has relatively uniform noise[10] and the dose received by the patient is reported to be reduced up to 34%.[11]

TCM has been proven to be effective in reducing doses in thoracic and abdominal CT examinations.[12] However, the utilization of TCM requires precise positioning of the patient at the iso-center.[13] Mis-centering can be risky since it leads to magnification or minification in the CT localizer radiograph[14] and leads to an increased dose received by the patient in some areas.[8] It can also lead to increased noise in some areas of the image.[15] These increases in dose and noise are due to the large number of photons attenuated by a thicker bowtie filter.[15,16]

The patient's positioning on the y-axis can be carried out by adjusting the height of the patient table. The iso-center of the patient is indicated by the laser marker.[17] In fact, mis-centering can occur on both axes (x- and y-axis), even though accuracy in the x-axis is easier to achieve.[18] The y-axis tends to be elevated from the iso-center more often than in the x-axis.[8,9] A study of automatic patient centering for MDCT showed that about 95% of patients undergoing thoracic and abdominal CT examinations had mis-centering in the y-axis.[19] Mis-centering has become a common problem and must be carefully considered since it impacts both the dose and noise distributions. Studies reported

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Authors' contribution:
A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

that patients tend to be mis-centered 23 mm in USA[18] and 22 mm below the iso-center in Iran[9].

Previous studies have addressed patient centering and developed specific algorithms to measure patient centering based on CT localizer radiographs,[8,9] axial CT images,[14] and images from a Kinect camera.[13,17] However, in the previous studies,[8,9,13,14,17,19] the software developed for the studies were not freely accessible to be implemented in clinical CT exams. Furthermore, in Indonesia, no studies of patient centering using clinical CT images have been reported yet. This study aims to develop software to determine the accuracy of centering in the x- and y-axis and to investigate the patient centering profile in three hospitals in Indonesia in order to obtain accurate positioning preference in CT examinations.

Materials and Methods

Patient image

In this study, we retrospectively studied a total of 268 patient images from three hospitals in Indonesia. The examination protocols included head, thorax, and abdomen. The exposure parameters used in each scanner are shown in **Table 1**, and the patient data is shown in **Table 2**. The TCM feature was activated on both thoracic and abdominal examinations, but not activated in the head examinations. Patients were grouped by gender and age to determine the centering profile in each group. The age grouping in the study referred to the ICRP report,[20] with 5-15 years being categorized as children and 15 years and over as adults.

Table 1. Exposure parameters used in each examination

Hospital	Scanner	Exposure parameters				
		Protocol	Tube voltage (kVp)	Rotation time (ms)	Tube current (mA)	Slice thickness (mm)
A	Siemens Somatom Definition AS 64 Slice	Head	130	1500	167	2
		Thorax	130	600	TCM	10
		Abdomen	130	600	TCM	10
B	Toshiba Aquilion 128 Slice	Head	120	320	750	1
		Thorax	120	500	TCM	2
		Abdomen	120	500	TCM	2
C	Siemens Somatom Definition AS 64 Slice	Thorax	120	1000	TCM	1
		Abdomen	120	1000	TCM	1

Table 2. Patient data used in each examination

Hospital	Scan protocol	Number of patients			
		By age		By gender	
		Paediatric	Adult	Male	Female
A	Head	3	42	25	20
	Thorax	1	27	16	12
	Abdomen	-	27	18	9
B	Head	1	39	21	19
	Thorax	2	26	8	20
	Abdomen	1	39	7	33
C	Thorax	-	30	20	10
	Abdomen	-	30	20	10
Total		8	260	135	133

Algorithm for automatic patient centering

We developed an algorithm to automatically determine the mis-centering in the x- and y-axis from axial images. Basically, mis-centering can be determined using a CT localizer radiograph or an axial CT image. However, CT localizer radiographs sometimes experience magnification or minification, so that mis-centering measurements become less accurate. This is not the case with axial CT images. Therefore, in this study, mis-centering was determined on the basis of axial CT images. For simplicity, the mis-centering measurements were based on the center of the patient, instead of the center of mass.

The algorithm of the automated patient's position on the examination table was integrated into IndoQCT.[21] The graphical user interface (GUI) for evaluating patient iso-center is shown in **Figure 1**, and the process of determining patient centering automatically is shown in **Figure 2**.

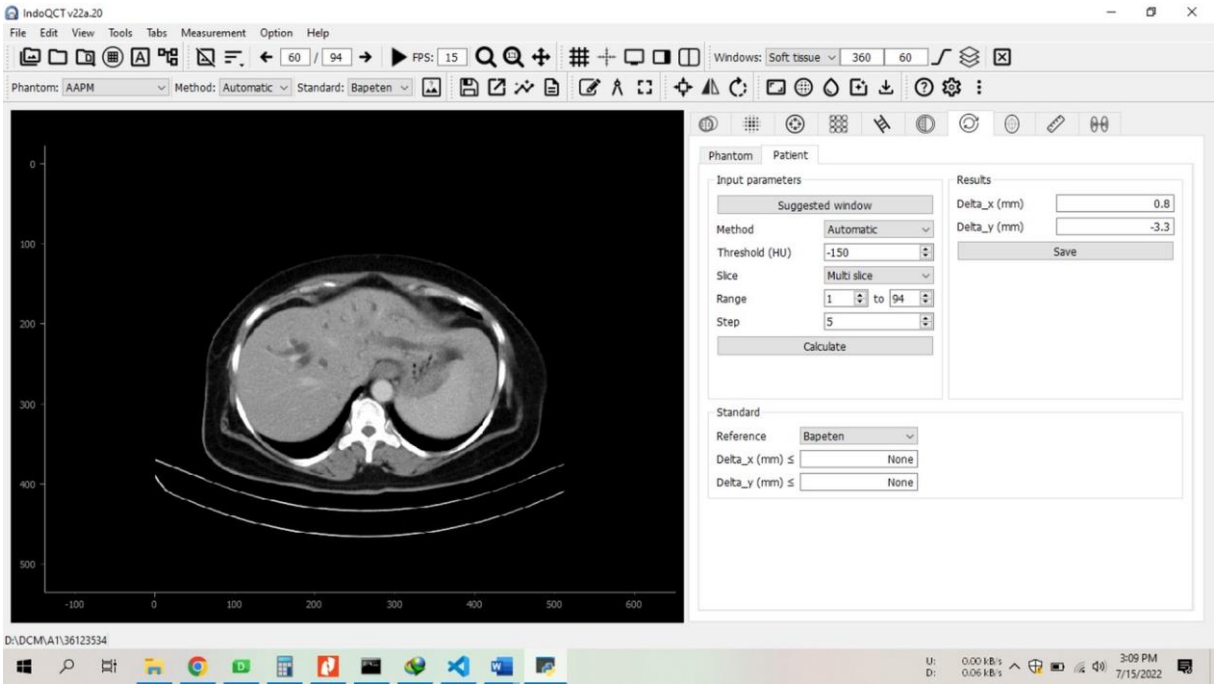


Figure 1. GUI of IndoQCT for automatic patient centering determination based on CT axial images.

The first step in determining patient centering was segmenting the patient boundaries (**Figure 2b**). Patient segmentation was started with thresholding of the patient image (**Figure 2a**). The thresholding used a value of -150 HU in order to obtain a binary image.[22] This value was selected because the background of the patient is air with a pixel value of about -1000 HU. Therefore, a threshold of -150 HU was sufficient to segment the patient from the background. However, the process of thresholding alone was not able to fully contour the patient, because of the presence of other objects inside the patient with HU values lower than -150, such as the presence of air within the patient. This can be overcome by differentiating between the objects within the patient and the patient's border, using edge detection to identify these objects and label them according to their areas. The largest area was identified as the patient border.[23]

After patient segmentation, we determined the patient's centroid on the x- and y-axis from the results of the segmented area (i.e. patient's body) (**Figure 2c**). Determination of the midpoint on both axes (x- and y-axis) used the following formulae:

$$x_{c,p} = \frac{1}{N}\sum_{i=1}^{N}(x_i) \quad \text{Eq. 1}$$

$$y_{c,p} = \frac{1}{N}\sum_{i=1}^{N}(y_i) \quad \text{Eq. 2}$$

The midpoint of the patient was subtracted to get the difference from the midpoint of the image array ($x_{c,i}$, $y_{c,i}$) with size of 512 × 512 (**Figure 2d**).

$$\Delta x = x_{c,p} - x_{c,i} \quad \text{Eq. 3}$$

$$\Delta y = y_{c,p} - y_{c,i} \quad \text{Eq. 4}$$

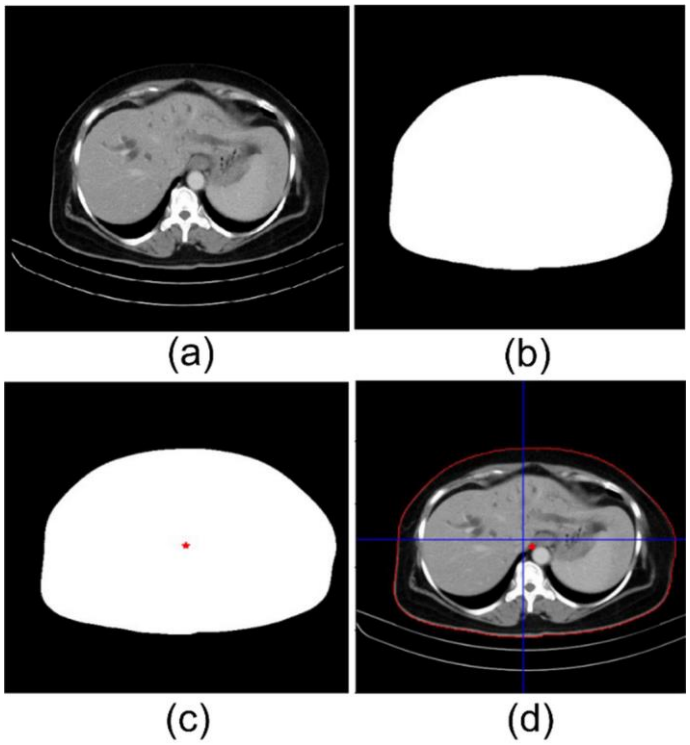


Figure 2. The process of automatic patient centering determination: (a) original image, (b) image after segmentation, (c) determination of the patient's center, and (d) result of centering image.

The difference between the two axes can be displayed to see the accuracy of centering the patient. This process was iterated automatically for all slices in each examination to obtain the centering profile of each patient. The accuracy of patient positioning should be within ±5 mm from the iso-center based on IAEA Human Health Series No. 19.[24]

Results

Our algorithm successfully detected the center of the patient images and determined the mis-centering in the x- and y-axis. Examples of mis-centering in x- and y-axis versus slice number from three hospitals are shown in **Figure 3**. It shows that the mis-centering value in the y-axis from the iso-center was higher than the mis-centering in the x-axis. The box-plots of patient centering in x- and y-axis in every hospital are shown in **Figures 4** and **5**, and the nominal mis-centering for each examination is tabulated in **Table 3**.

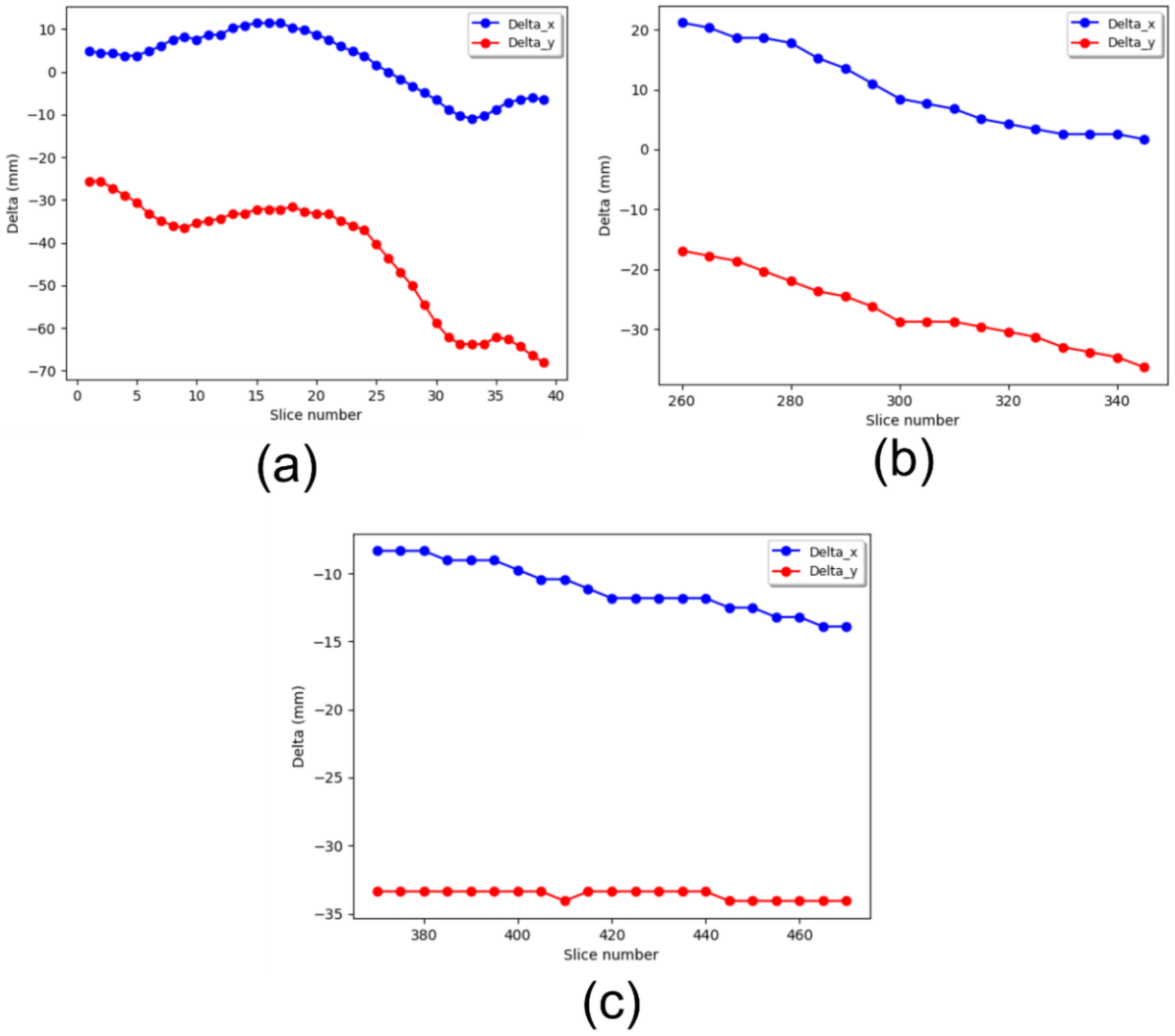


Figure 3. Examples of the mis-centering profile versus slice number for the abdominal examinations of one patient at: (a) Hospital A, (b) Hospital B, and (c) Hospital C. The mis-centering in the x- and y-axis is represented by the blue and red lines, respectively.

Table 3. The value of patient mis-centering from three hospitals in Indonesia.

Hospital	Examination Protocol	Mis-centering			
		x-axis		y-axis	
		Mean ± SD (mm)	Range (mm)	Mean ± SD (mm)	Range (mm)
A	Head	-0.4 ± 3.1	-6.5 to 6.1	-5.9 ± 9.2	-32.7 to 7.6
	Thorax	-1.7 ± 5.6	-12.2 to 10.2	-15.1 ± 19.1	-62.7 to 32.8
	Abdomen	-0.9 ± 6.5	-17.6 to 14.5	-19.7 ± 14.6	-62.1 to 16.2
B	Head	-1.6 ± 3.7	-7.0 to 10.4	-12.5 ± 3.2	-14.3 to 0.5
	Thorax	-1.0 ± 4.5	-21.4 to 4.2	-14.4 ± 14.1	-40.5 to 6.3
	Abdomen	-0.9 ± 2.5	-6.0 to 3.9	-11.5 ± 14.3	-44.9 to 9.6
C	Thorax	-0.6 ± 3.1	-5.6 to 7.9	-26.1 ± 16.8	-53.1 to 6.2
	Abdomen	0.2 ± 4.5	-11.1 to 10	-25.4 ± 16.0	-51.0 to 6.1

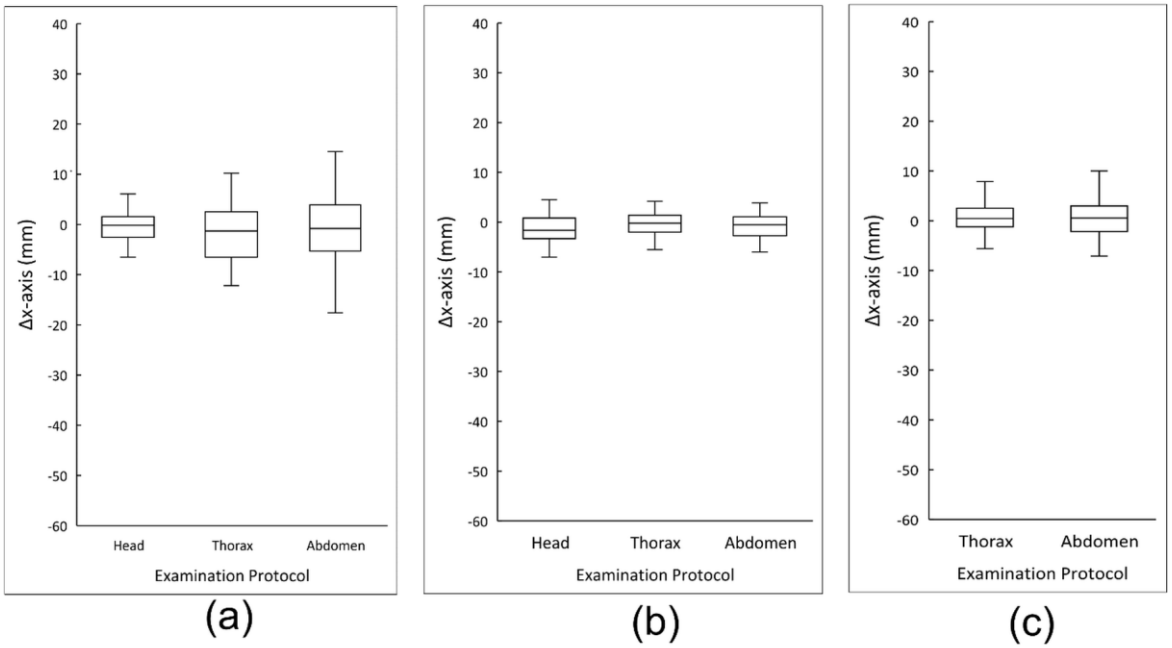


Figure 4. Box-plots of x-axis mis-centering using different protocols at: (a) Hospital A, (b) Hospital B, and (c) Hospital C. Head examination data at Hospital C were not available.

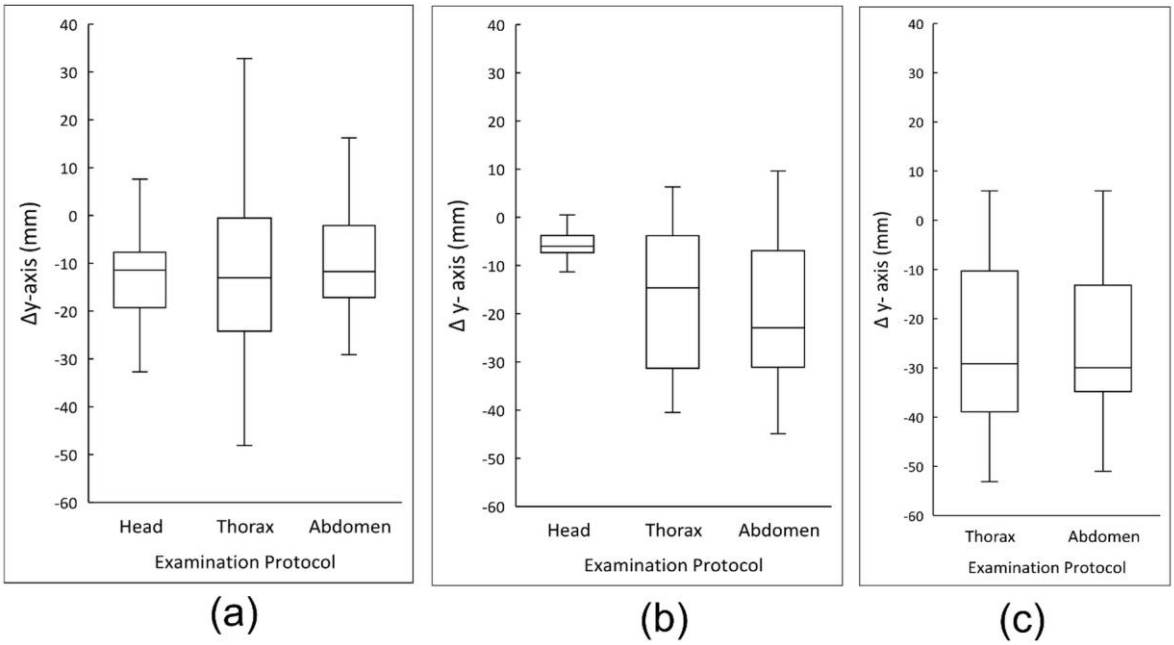


Figure 5. Box-plots of y-axis mis-centering using different protocols at: (a) Hospital A, (b) Hospital B, and (c) Hospital C. Head examination data at Hospital C were not available.

Patient centering in the x-axis was relatively accurate. We found that 78% of patients centered with a deviation less than 5 mm (≤5 mm) from the iso-center, while only 22% were mis-centered by more than 5 mm. However, in the y-axis, most of the patients are improperly located from iso-center. 82% were mis-centered (difference >5 mm), and only 18% of patients were centered accurately.

The x-axis positioning errors in hospitals occurred within a narrow range. In hospital A, patients were positioned with -0.4 (±3.1) mm for the head, -1.7 (±5.6) mm for the thorax, and -0.9 (±6.5) mm for the abdomen. The centering errors in hospital B were 1.6 (±3.7) mm for the head, -1.0 (± 4.5) mm for the thorax, and -0.9 (±2.5) mm for the abdomen. The smallest values were obtained from hospital C, with -0.6 (±3.1) mm and 0.2 (±4.5)

mm for thoracic and abdominal examinations, respectively. There was a tendency from all three hospitals to improperly locate patients 5-10 mm away from the iso-center in all examinations.

The profiles of the y-axis centering yielded a wider range. Patients in hospital A were placed -5.9 (±9.2) mm for the head, -15.1 (±19.1) mm for the thorax, and -19.7 (±14.6) mm for the abdomen lower than the gantry's iso-center. Most of the patients in all examinations were positioned 10-30 mm away from the center of the gantry. Hospital B patients were located under the center of the gantry, -12.5 (±3.2) mm, -14.4 (±14.1) mm, and -11.5 (±14.3) mm for examinations of the head, thorax, and abdomen, respectively. Most of the patients were placed <10 mm for head examinations and 10-30 mm for thoracic and abdominal examinations away from the y-axis center. A different profile was found in Hospital C. The centering of Hospital C was lower than the other two hospitals with -26.1 (±16.8) mm for the thorax and -25.4 (±16.0) mm for the abdomen. Most of the patients were placed >20 mm below the center of the gantry.

We found there was a small discrepancy in mis-centering between male and female patients, with x- and y-axis mis-centering of 0.5 mm and 1.2 mm, respectively. The average pediatric patient was mis-centered ±4.8 mm in the x-axis and ±20.0 mm in the y-axis, while adult patients had lower values of ±0.5 mm and ±15.4 mm in x- and y-axis, respectively.

Discussion

This study introduced a simple tool for evaluating patient centering from axial CT images of the patient and evaluated the patient centering profile on CT scan examinations in three hospitals in Indonesia. A previous study reported that the determination of patient centering in the iso-center gantry is highly dependent on the accuracy of determining the iso-center by medical personnel.[9] Determination of the iso-center is conducted by raising and lowering the examination table and is based on visual estimation by the medical personnel. Although many researchers have developed tools to determine the iso-center of patients automatically,[17,18,25] these are still not widely practiced in the field, especially in developing countries like Indonesia, and patient centering remains very subjective.

Determination of patient centering can be performed on CT localizer radiographs,[8,9] axial CT images,[26,27] or images from a Kinect camera.[13,17] Determination of patient centering from CT localizer radiographs is less accurate because localizer radiographs sometimes experience magnification or minification. Using an axial CT image is more accurate.[26,27] The CT numbers within the axial images are first converted to mass density, and then the center of mass is determined. However, the measurement of patient centering from axial CT images has a weakness because the measurements can only be done after scanning is completed. This technique cannot be used directly for setting patient centering at the time the patient is being scanned. Patient centering measurements with Kinect cameras also have advantages and disadvantages.[13] The advantage is that the determination of patient centering can be performed without the use of ionizing radiation and prior to scanning the patient, but the disadvantage is that the accuracy is quite low.

In this study, for simplicity, the mis-centering measurements were from axial CT images. The center of the patient was automatically determined based on the center of the axial CT image, instead of the center of mass.[26,27] Both the center on the y-axis and the center on the x-axis were measured automatically in this study.

We found that for all three hospitals, there is a tendency for most patients to be placed under the iso-center of the gantry. For the mis-centered patients, 49% were placed 10–35 mm away from the gantry iso-center. This tendency was also investigated by Habibzadeh et al.[9], Toth et al.[19], Oladuni et al.[26], and Kaasalainen et al.[27] who found that the patient was positioned about 17-35 mm below the iso-center.

We found that the error in the x-axis centering is smaller than the y-axis, in agreement with previous studies.[19,27] For all the mis-centered patients, 67% were positioned 5–10 mm away from the iso-center (with a mean of 6.7 mm).

Improper patient positioning in the gantry has been known to cause errors in estimating patient size.[14] This has an impact on the prediction error of the automatic TCM and causes the $CTDI_{vol}$ to be larger.[26] High $CTDI_{vol}$ values will result in higher doses to the patient, so the function of TCM to reduce the dose to the patient will not be achieved.

Gudjonsdottir et al.[28] showed that patient positioning 30 mm below the gantry iso-center resulted in a 56% increase in surface dose due to a 25% malfunction of the TCM. Another study[9] found that there was a 12-18% increase in surface CTDI from mis-centering at the 30 mm position. Increases in $CTDI_{vol}$ of 38% and 23% were also reported by Kaasalainen, et al.[26] in a patient position 60 mm below and above the iso-center.

We found that there was no significant difference between the mis-centering of male and female patients, but there is a slight difference between pediatric and adult patients for both axes. The values obtained are similar to previous studies[14,19], which showed smaller patients have a higher tendency to have mis-centering than larger patients. This deviation carries a risk since mis-centering of ±60 mm in pediatric patients causes a dose increase of 34%,[11] which is very significant since pediatric patients have a greater life expectancy.

This study indicates that the practices in determining accurate patient centering need to be improved. In Indonesia, the determination of patient centering still uses visual estimation by medical personnel. Since the x-axis centering is more easily achieved, more attention to the y-axis centering must be considered to get a more accurate center position. We recommend raising it by about 10-35 mm from the current practice.

Patient mis-centering may occur due to a lack of training and understanding of the importance of centering. Providing education, talk sessions with experts, and field studies can all help to establish a better understanding among medical personnel. A study conducted by DeWeese et al.[29] on providing education and training to medical personnel, showed an increase in accuracy in patient positioning. The number of medical personnel who positioned the patient within ±10 mm below the iso-center increased from 23% to 34%, while improper positioning more than 30 mm below the iso-center decreased from 36% to 20%. This indicates that special training in patient centering for medical personnel can minimize mis-centering.

There are several limitations to this study. First, this study is conducted with retrospective images of patients and a limited number of hospitals. Second, we did not have sufficient data about patient dose and noise so we were not able to report on the effect of mis-centering on the dose and noise in this study. Third, this study only examines patient centering using one method, i.e. by determining the center of the axial CT image. Comparative studies between available methods will be very important in future studies.

Conclusions

We have successfully developed software for investigating patient centering based on the patient axial CT image. The mis-centering of patients was observed in three hospitals in Indonesia for various examinations (head, thorax, and abdomen). Most patients tend to be placed below the iso-center by about 10-30 mm.

Acknowledgments

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Conflict of interest

Choirul Anam, Ariij Naufal, and Geoff Dougherty are the developers of IndoQCT, a software for CT image quality evaluation. This software is not commercially available yet. Contact anam@fisika.fsm.undip.ac.id for more information.

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