The impact of pitch values on image quality and radiation dose in an abdominal adult phantom using CT

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Abstract

Purpose: To identify the impact of different pitch values on image quality and effective radiation dose for axial and coronal plane in abdominal adult CT.

Methods and materials: Three scans were conducted on an abdominal phantom using a Toshiba Aquilion 16-slice CT scanner with three different pitch values: standard (0.938), detail (0.688) and fast (1.438). Slices were taken from the upper, middle and lower abdomen in the axial plane and anterior, middle and posterior in the coronal plane. The six different anatomical structures were liver, intrahepatic vessels, spleen, pancreas, kidneys and renal vessels, retroperitoneum, aorta and vena cava. A two-alternative forced-choice (2AFC) method was used to evaluate images for each pitch with 8 observers using a 3-point Likert scale. SNR was calculated in every plane, slice and pitch factor using the ImageJ software. To estimate effective radiation dose the CT Expo software was used.

Results: Detail pitch factor provides superior image quality compared to standard in axial plane when evaluating the liver (p<0.034) and pancreas (p=0.008). However, the results for spleen, kidney, renal vessels, retroperitoneum, aorta and vena cava are not significant when comparing detail vs standard. Standard provides a 26.3% reduction in effective radiation dose (mSv) compared to detail. Fast had the worst image quality in both the axial and coronal plane but the lowest dose. In the coronal plane, standard was superior to both detail (p=0.026) and fast (p=0.023) in terms of image quality. The differences in SNR results were not significant except in standard vs detail in the coronal plane (p=0.03).

Conclusion: Detail pitch factor provides superior image quality to standard and fast in the axial plane. Standard had superior image quality to both detail and fast in the coronal plane. The augmentation of effective doses has been inversely proportional to the pitch factors. The most irradiant pitch mode was detail and the less was fast.

Introduction

Since its development in the 1970s, the number of computed tomography (CT) examinations has grown rapidly. Nowadays, CT is responsible for 60-70% of the patient radiation dose received by radiological examinations (1). CT abdomen scan is one of the most frequently performed examinations and its effective dose varies between 2.6 and 28.7 mSv per year for different European countries (2). Radiation dose can cause stochastic effects, which occur by chance and are related to genetic modification and pathogenesis of cancer (3). To minimise the occurrence of stochastic effects, it is important to limit the radiation dose as much as possible whilst maintaining adequate image quality for diagnostic purpose, as suggested by ALARA (4).

Different parameters on CT can be used to reduce the patient radiation dose. One of these parameters is the pitch, which is defined as the table movement per 360 degrees rotation time divided by the beam width (5). The use of a high pitch can reduce the radiation dose and the scan time (5). When the CT scan is acquired within a shorter time, possible motion artefacts can be reduced. This is useful when scanning areas in which there is a lot of involuntary movement, such as the cardiac or the lung regions. However, it is important to consider the effect of a higher pitch on image quality, particularly on the spatial resolution (6).

On the other hand, a low pitch might be chosen when high image quality is needed. A consideration has to be made when deciding whether the effective radiation dose counterbalances the image quality. This study will estimate the $CTDI_{vol}$, DLP, effective radiation dose and the image quality in order to make a justification for the use of a high, standard or low pitch.

The research question of this study was: "How do different pitch values affect image quality and effective patient radiation dose in coronal and axial planes in abdominal CT?"

The research aim is to: identify differences in image quality and radiation dose due to the use of different pitch values for coronal and axial planes in abdominal CT.

The objectives were:

- To acquire CT images using abdominal phantom with three different pitch factors
- To give physical and perceptual measurements on image quality
- To estimate differences in $CTDI_{vol}$, DLP and effective radiation dose.

Methods

Image Acquisition

This study was performed in the Susan Hall Imaging Facility at the University of Salford. An adult-sized, abdomen anthropomorphic phantom (PH-5 CT Abdomen Phantom, Kyoto Kagaku Company, Japan) was scanned on a Toshiba Aquilion 16 MDCT scanner (Toshiba Medical Systems, Minato-ku, Japan), configured according to commonly used parameters in clinical practice. To keep the results relevant to a clinical setting, automatic tube current was used. The tube voltage was fixed to 120 kV and a rotation time of 0.5 s was set. Three different pitch values were used; fast (pitch factor 1.438), standard (pitch factor 0.938) and detail (pitch factor 0.688).

The scan range was 261 mm and covered the entire upper abdomen. Images were acquired with a thickness of 1 mm and reconstructed to 3 mm thick slices, resulting in 88 images.

Perceptual image quality evaluation

The European Guidelines (7) were used to inform the development of criteria for the visual image evaluation. The acquired axial volume for each pitch factor was reconstructed in the coronal plane. Both the axial and coronal planes were then divided into three different slice regions focusing on the anatomical structures that were included in the European Guidelines criteria. Upper axial slices and anterior coronal slices contained the spleen, liver parenchyma and intrahepatic vessels. The middle slices in axial and coronal planes contained the pancreas, kidneys and renal vessels. Lower axial slices and posterior coronal slices contained the aorta, vena cava and retroperitoneum.

Observers were asked to score the anatomical structures for sharpness of reproduction. To ensure that they would rate the images appropriately, a short presentation was given before the start of the image scoring. This presentation showed the criteria, the selected anatomy and an explanation of the rating system (Likert). The selected images were then scored against images acquired with a different pitch but within the same slice region using two-alternative forced-choice (2AFC) method. This method allowed the observers to rate the evaluated image as worse, equal or better compared to the control image. A 3-point Likert scale was chosen, as it often forces the observer into a particular direction (better, equal or worse). This removes the ambiguity which exists in a 5-point scale where the difference between 'better' and 'much better' is often difficult to distinguish (8) or might differ between observers (9). Each criteria could be scored as -1 meaning worse, 0 meaning equal and +1 meaning better. All the scores from different observers were combined and divided by the number of observers to obtain a mean score for all the different structures.

The researchers windowed the images within guidelines (10) ensuring that the images were visualised under the same settings for all observers. Two NEC MultiSync monitors model EA243WM were calibrated to the DICOM grey scale standard. Both monitors were switched on for twenty minutes before use, as recommended by the manufacturer (10) and had their parameters adjusted according to the recommended settings: 100% of brightness, 50% of contrast, auto-brightness and eco modes off, and colour scheme in native mode. Lighting conditions were dimmed and consistent throughout the observations. The results given by the observers were inserted into a spreadsheet.

Physical Image Quality Evaluation

A physical evaluation of the image quality was made using RadiAnt DICOM Viewer. Multiple regions of interest were selected in the anatomical structures described in European Guidelines. The standard deviation was measured in the exact same region for all the different pitches using RadiAnt DICOM

Viewer with the Hounsfield unit to ensure accuracy. To minimise bias, the mean of multiple regions within the same slice was calculated instead of using a single region of interest. The mean attenuation value was acquired in the same way. The signal-to-noise ratio (SNR) was then calculated using the mean attenuation value and dividing it by the standard deviation (11), as shown in the equation below.

$$SNR = S/\sigma \quad (1)$$

Observers

In order to have a visual/perceptual evaluation, eight observers were invited to analyse the images. They were included in this study based on their level of experience in CT and their knowledge of the cross-sectional anatomical structures. Observers were asked how many years of experience they had, whether their eyesight was corrected with glasses, contact lenses or other means, and when they last underwent an eyesight test. The eight observers consisted of three males and five females. The mean age of those selected was 39. The experience of the observers with CT ranged between 1 and 28 years. Five of the observers used glasses or contact lenses and the other three did not require any eyesight correction. All of the observers had their eyes checked within the last six months.

Calculation of $CTDI_{vol}$, DLP and effective dose

The different technical parameters such as the tube current and overall scan time were acquired from the CT scanner after the scan had concluded. The Monte Carlo based dose calculation software CT-Expo v. 2.3.1 (12) was used to calculate $CTDI_{vol}$, DLP and effective dose. The effective dose was calculated according to ICRP 103 (3) and transferred to a spreadsheet.

Statistical Analysis

Data was transferred to SPSS (13) for statistical analysis. Cronbach´s Alpha was used to measure the internal consistency of the observers. Intraclass correlation coefficient was used as a measurement for the reliability of the ratings of the observers at 95% confidence level. A paired Student's t-test and Wilcoxon test was also used to determine the *p*-value with a significance level of 0.05.
Mean and standard deviation were calculated for the perceptual image evaluation ratings and a normality test was performed (Shapiro-Wilk test).
After calculating the SNR values, the same normality test was utilised to evaluate data distribution.
The significance was calculated between all SNR values and a *p*-value less than 0.05 was considered statistically significant.

Results

Internal consistency and intraclass correlation coefficient

Internal consistency was measured between the eight participating observers using Cronbach's Alpha. The Alpha value was 0.937 for axial images and 0.955 for coronal images, indicating an excellent internal consistency within the observer's group.
For the axial plane, intraclass correlation coefficient indicates highly reliable measures between observers with a range of 0.879-0.974 (95% confidence interval). Concerning the coronal plane, the range was 0.915-0.981 (95% confidence interval). Inter-item correlations between observers ranged from 0.287 to 0.949, indicating the existence of a correlation between the eight observers' choices. Although the inter-item correlations were lower for one observer (0.287), the decision was made to include this observer into the study. This was done because the observer fitted the criteria and the same situation could occur in a clinical setting.

Perceptual image quality evaluation

The mean and standard deviation (SD) of the perceptual image quality scoring were calculated. Both standard and detail pitch modes performed significantly better than fast mode in both the axial and coronal plane.
The overall ratings obtained for subjective perceptual image quality evaluation showed that there was no statistically significant differences between the overall abdomen images obtained with standard and detail pitch acquisition modes in the axial plane. In spite of that, after analysing each criteria separately, detail

Visually sharp reproduction of the following structures	Standard vs. Detail		Detail vs. Fast		Fast vs. Standard	
	Axial	Coronal	Axial	Coronal	Axial	Coronal
Liver parenchyma and vessels	-0.750	1.000	1.000	0.125	-0.625	-1.000
Spleen parenchyma	-0.375	0.875	1.000	0.000	-0.250	-1.000
Pancreatic contours	-0.875	1.000	1.000	0.875	-1.000	-1.000
Kidneys and renal vessels	0.500	1.000	0.750	0.875	-0.875	-1.000
Retroperitoneum	0.000	0.750	0.625	0.625	-0.875	-0.625
Aorta and vena cava	0.325	0.750	0.750	0.375	-0.750	-0.625
Mean ± Standard Deviation	-0.208 ± 0.552	0.896 ± 0.123	0.854 ± 0.166	0.479 ± 0.374	-0.729 ± 0.267	-0.875 ± 0.194
p-value	p = 0.42	p= 0.026	p= 0.026	p = 0.042	p= 0.001	p = 0.023

Table 1. Subjective image scoring.

Figure 1. Axial images for Detail, Standard and Fast pitches, respectively.

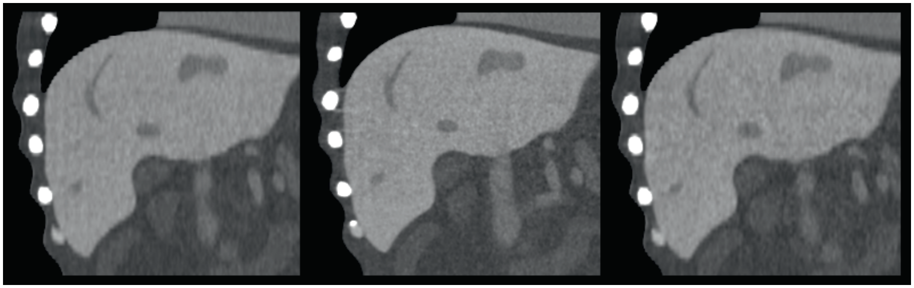

Figure 2. Coronal images for Detail, Standard and Fast pitches, respectively.

Table2. Standard vs. Detail (axial) p-values.

Visually sharp reproduction of the following structures	p-Value
Liver parenchyma and vessels	0.034
Spleen parenchyma	0.180
Pancreatic contours	0.008
Kidneys and renal vessels	0.102
Retroperitoneum	0.956
Aorta and vena cava	0.351

Table 3. Average SNR values for the three pitch modes.

Slice Group	Axial			Coronal		
	Standard	Detail	Fast	Standard	Detail	Fast
Upper	7.36	11.00	7.64	9.38	13.22	8.38
Middle	6.32	5.57	4.59	7.66	14.33	6.00
Lower	5.37	3.95	3.65	3.37	4.72	3.20

Pitch Modes	Scanner Doses		Estimated Doses (CT-Expo)		
	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Eff. Dose (mSv)
Standard	25.3	585.8	23.1	608.0	10.0
Detail	34.4	728.2	31.5	829.0	13.6
Fast	20.6	534.9	15.6	409.0	6.7

Table 4. Radiation doses for the three pitch modes.

pitch performed better for liver parenchyma, vessels image and pancreatic contours as well. These results are shown in **table 2**.

Figure 1 shows the upper axial slices using the three different pitch factors.

For the coronal reconstruction (**Figure 2**), standard pitch mode generated images with better quality than both detail and fast modes (p=0.026 and p=0.023, respectively). Detail was slightly better than fast and although there was a high standard deviation for the scores, the p-value showed a statistically significant difference.

Physical image quality evaluation

Mean SNR values for the three pitch factors are shown in (**table 3**). No difference amongst the SNR values for axial images was found, considering that all calculated p-values were higher than 0.05. However, for coronal images there was a significant difference in SNR between standard and detail pitch acquisition modes (p = 0.03).

Calculation of $CTDI_{vol}$, DLP and effective dose

In **table 4**, both the values acquired from the CT scanner and the calculated values were included.

The most common values for $CTDI_{vol}$ and DLP were recorded for 72% of the 36 European countries (14). In literature, it was found that the mode $CTDI_{vol}$ was 25 mGy and the mode DLP was 800 mGy.cm. $CTDI_{vol}$ values found in this study for standard (23.1 mGy) and fast (15.6 mGy) were below the modal $CTDI_{vol}$. Detail (31.5 mGy) was above. The DLP values for standard (608 mGy.cm) and fast (409.0 mGy.cm) pitch were below the modal DLP. Detail pitch (829 mGy.cm) was above the modal DLP for European countries.

The fast pitch resulted in the lowest effective dose, the detail pitch resulted in the highest effective dose and standard had a value in between both.

Discussion

The overall perceptual image quality evaluation showed no statistically significant differences between standard and detail acquisition modes in the axial plane. This corresponds with available literature which suggests perceptual image quality remains equivalent when images acquired with different pitch are evaluated (15-19). Standard acquisition mode was worse than detail for the liver parenchyma and vessels and pancreatic contours. Nonetheless, it's important to keep the ALARA principle in mind. This means that the technical parameters that produce low dose, which may acquire a comparable image quality, can be chosen to reduce radiation dose without compromising diagnostic value of the image. For example, a general abdomen CT examination might be made with the standard pitch mode to acquire the same overall image quality with a lower radiation dose than with a detail pitch mode. On the other hand, our results also suggest that if the purpose of the abdominal CT scan is to analyse the liver parenchyma and vessels or the pancreatic contours, a detail pitch mode could be a better choice.

Despite its poor image quality score compared to standard and detail, a potential benefit of using a fast pitch is reducing the effective radiation dose. Fast pitch also limits the potential motion artefacts in specific population subgroups, such as children, that tend to struggle holding their breath and remaining stationary (20).

For the coronal plane, the observers scored standard pitch acquisition mode as better than both the detail and fast modes. A possible explanation is the presence of a stair-step artefact on the coronal images (**figure 2**). This artefact likely appeared due to the non-overlapping reconstruction intervals which were used (21). The reconstruction software is likely optimised for a standard pitch, which could also explain the higher image quality scores.

In researched literature, higher pitches generate images with increased objective noise and lower signal-to-noise ratio (SNR) (15; 18; 22). However, the results in our study does not show a statistically significant difference for SNR values in the axial plane with all *p*-values being greater than 0.05.

In the coronal plane the results are similar although, when comparing standard vs detail there is a statistically significant difference (p=0.03). Even though detail has a higher SNR, observers still rated the image as worse compared to the images with a standard pitch. A possible explanation is the presence of the stair-step artefact in the coronal plane. Verdun et al. describe that the noise in a CT image only has a minor dependence on the pitch (11) and this could explain the similar SNR levels for different pitch factors (**table 3**).

The differences between scanner doses ($CTDI_{vol}$, DLP) and the estimated doses from CT-Expo might be due to errors of the CT-Expo software, considering it allows a range to ± 15% (12). Furthermore, the z-axis dose modulation might be different when using the CT-Expo software compared to the CT scan because the used phantom might differ from the reconstruction of the abdomen in the CT-Expo software. As expected, the augmentation of effective doses is inversely proportional to the pitch factors. The most irradiant pitch mode is detail and the less is fast, this is in accordance with found literature (15; 17; 18; 20). Even though the recorded $CTDI_{vol}$ and DLP values indicate that detail pitch is above the common recorded values, some factors should be taken into consideration. The most common value for $CTDI_{vol}$ and DLP in abdomen CT in European countries is a combination of the values acquired for different abdomen scans. This means that different parameters were used for the scans, for instance different pitch factors. Furthermore, different CT scanners from different manufacturers were included. Another factor that influences the mean values is the difference between patients. The discrepancy between these values should be taken into consideration before forming a conclusion about the values found in this study.

Using a phantom creates an artificial and controlled research environment which is usually not the same as seen in clinical practice although, a phantom allows for a high level of control which is a benefit in experimental science.

Study limitations

This study has some limitations that need to be considered. Furthermore, the results of our study refer specifically to a 16-slices CT Toshiba scanner using filtered back projection (FBP) reconstruction method. Iterative reconstruction algorithms are being studied to be an alternative in overcoming the conflict between image reading quality and high radiation doses (23; 24). Although the observer data showed a strong interrater agreeability, qualitative image analysis can be subjective. This should be taken into consideration when implementing these results. No identical comparison between same pitch images (e.g. detail vs detail) was made during image evaluation, therefore it is impossible to determine whether the results are valid. Despite this, the large number of observers participating in our study revealed a high level of internal consistency.

Conclusion

Our results suggest that in the axial plane standard (0.938) and detail (0.688) pitch factors are superior to a fast (1.438) pitch factor in terms of image quality; however, the effective radiation dose for the fast pitch was 33% lower than standard and 50.8% lower than detail. Detail was superior to standard pitch when looking at the liver and pancreatic contours. No significant differences were noted in the spleen, kidney, renal vessels and lower abdomen between these pitches. Standard had a lower dose of 26.3% compared to detail.

In the coronal plane standard was superior to both detail and fast in terms of image quality and fast was worse than detail. No significant difference was noted between SNR values in the axial plane, except between standard and detail (p=0.03) in the coronal plane.

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