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Kertas Asli/*Original Articles*

Evaluating the Relationship of Body Mass Index and Waist Circumference on the Image Quality of Abdominal Computed Radiography
(Menilai Hubungan Indeks Jisim Badan dan Lilitan Pinggang pada Kualiti Imej Radiografi Berkomputer Abdomen)

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ABSTRACT

Body sizes of patients undergoing x-ray examination vary in body mass index (BMI) and waist circumference (WC). This study aimed to evaluate the relationship between BMI and WC on the image quality of abdominal computed radiography (CR). Anteroposterior supine abdomen projection was conducted on 69 patients from Hospital Raja Perempuan Bainun, Ipoh using a Siemens Multixtop general x-ray unit, and the images were processed with CR Carestream Direct view Max. Samples were categorised into normal BMI (n = 23), overweight (n = 23) and obese (n = 23). Image quality was measured quantitatively in signal-to-noise ratio (SNR) and qualitatively by visual grading analysis (VGA) based on the Commission of the European Communities (CEC) image criteria. Data were analysed by analysis of variance (ANOVA) and Pearson's correlation for comparison and determining the relationship among BMI, WC and image quality. Results showed a significant difference ($p < 0.01$) in image quality of VGA_{mean} (normal = 4.40 ± 0.15, overweight = 4.35 ± 0.13, obese = 4.03 ± 0.34) and SNR_{mean} (normal = 60.79 ± 2.19, overweight = 59.66 ± 1.68, obese = 55.78 ± 4.31). A moderate to high negative correlation existed between SNR ($r = -0.73$), VGA ($r = -0.7$) with BMI ($p < 0.01$) and between SNR ($r = -0.83$), VGA ($r = -0.79$) with WC ($p < 0.01$). This study suggests that WC has a higher negative linear relationship than BMI and can be used as an effective image quality predictor for abdominal CR examination.

Keywords: Computed radiography; abdomen; image quality; waist circumference; BMI

ABSTRAK

Saiz badan pesakit yang menjalani pemeriksaan sinar-x berbeza mengikut indeks jisim badan (BMI) dan lilitan pinggang (WC). Objektif kajian ini adalah untuk menilai hubungan antara BMI dan WC pada kualiti imej abdomen pemeriksaan radiografi berkomputer (CR). Projeksi anteroposterior supin abdomen telah dijalankan pada 69 orang pesakit di Hospital Raja Perempuan Bainun, Ipoh menggunakan unit sinar-x am Siemens Multixtop dan imej-imej diproses dengan pemproses CR Carestream Direct Max. Sampel dikategorikan kepada BMI normal (n = 23), berat badan berlebihan (n = 23), dan obes (n = 23). Kualiti imej diukur secara kuantitatif dalam isyarat kepada nisbah hingar (SNR) dan secara kualitatif, analisis penggredan visual (VGA) berdasarkan kriteria imej Suruhanjaya Eropah (CEC). Data dianalisis menggunakan analisis varians (ANOVA) dan korelasi Pearson untuk perbandingan dan menentukan hubungan antara BMI, WC dan kualiti imej. Keputusan menunjukkan perbezaan yang signifikan ($p < 0.01$) dalam kualiti imej VGA_{min} (normal 4.40 ± 0.15, berat badan berlebihan 4.35 ± 0.13, obes 4.03 ± 0.34) dan SNR_{min} (normal 60.79 ± 2.19, berat badan berlebihan 59.66 ± 1.68, obes 55.78 ± 4.31). Wujud korelasi negatif yang sederhana hingga tinggi antara SNR (r −0.73), VGA ($r = -0.7$) dengan BMI ($p < 0.01$), dan antara SNR ($r = -0.83$), VGA ($r = -0.79$) dengan WC ($p < 0.01$). Kajian ini mencadangkan bahawa WC mempunyai hubungan linear negatif yang lebih tinggi dari BMI dan boleh digunakan sebagai peramal kualiti imej yang berkesan bagi pemeriksaan CR abdomen.

Kata kunci: Radiografi berkomputer; abdomen; kualiti imej; lilitan pinggang; BMI

INTRODUCTION

The Radiological Society of North America demonstrated that diagnosis of health problems associated with obesity is increasingly becoming challenging. Radiologists reported that body habitus limited has resulted in poor-quality images appearing repeatedly in abdominal ultrasonography (US) followed by chest radiography (CXR), abdominal radiography, abdominal computed tomography (CT), chest CT and magnetic resonance imaging radiology reports (Uppot et al. 2005). Another study found that CXR and US are most affected by obesity among the imaging modalities (Reynolds 2011).

Abdominal radiography plays a crucial role in early diagnosis in the imaging centre without a CT scanner and screening of stones, bowel abnormalities or free intra-abdominal air (Alshamakhi et al. 2009; Rosen et al. 2000). In the follow-up studies of ureteric stone, abdominal radiography is recommended to be the choice of study due to the high radiation dose of CT (Mansouri et al. 2015; Zagoria et al. 2001). In the hospital where the current study was conducted, the number of general radiography examination by body parts for Malaysian Ministry of Health radiology examination census showed that abdomen x-ray examinations performed in 2016 was 15,235 cases only second to CXR with 57,159 cases (HRPB radiology census form: PER SS-RA 201 accessed on 18.05.2019).

Several studies on image quality of *posteroanterior* (PA) projection versus *anteroposterior* (AP) projection of abdominal and lumbar radiography showed conditional differences in image quality (Brennan & Madigan 2000; Nic An Ghearr & Brennan 1998; Davey & England 2015). Brennan & Madigan (2000) found no significant difference in PA projections compared with AP counterparts in their qualitative evaluation of image quality of lumbar vertebra. The study was conducted on the sample of female patients, weighing 70 ± 5 kg and between 1.55 and 1.75 meter in height, with the x-ray radiographic voltage (kVp) of 75 kVp throughout the study. By contrast, Davey and England (2015) reported a slight reduction in the image quality at high kVp settings employing a lumbar spine anthropomorphic phantom as the sample at 70-110 kVp increments. Nic An Ghearr & Brennan (1998) studied abdominal radiography and claimed no significant image quality difference in PA compared with AP projection on the female patients weighing 66 ± 10 kg with the height between 1.55 and 1.70 meter using fixed 66 kVp.

Other previous image quality and radiation dose studies using BMI have been also conducted in relation to patient size, exposure factors and the type of equipment used (Reis et al. 2014; Uffmann et al. 2005; CEC 2014; Osei & Darko 2013; Ladia et al. 2016). Single BMI studies using a single phantom as subject, for instance in Reis et al. (2014) study, an anthropomorphic phantom was used to compare the image quality and effective dose applying the 10 kVp rule with manual mode acquisition and automatic exposure control (AEC) mode in CXR of PA projection. While for BMI, Ladia et al. (2016) study of the effect of BMI on patient dose in paediatric radiography on patients aged 5 to 6.5 years and categorized into normal and overweight. Osei & Darko (2013) investigated patient effective doses from radiological examination and for abdominal radiography dose reference level in which 50 adult patient were taken as samples with the body thickness from 11-43 cm.

All the aforementioned studies showed the importance of relationship between body size and the image quality with regard to radiation dose and exposure factors. It also indicated that the continuous needs or justification for study of body size and image quality relationship in radiography. Furthermore understanding the BMI and WC relationship on the abdominal CR image quality is important to reduce retake of images and conduct correct diagnosis, which save additional costs due to wastage of resources, additional unnecessary radiation and patient discomfort. The final image quality produced in radiography examination are governed by many factors, such as grid ratio, detectors efficiency; influenced by the kVp, filtration, patient thickness (Willis 2002), radiography technique in patient positioning and other technical factors. To date, we have not found any previous studies indicating the relationship between BMI and image quality of abdominal CR. Therefore, this study aimed to evaluate the relationship of BMI and WC on the image quality of abdominal CR.

EXPERIMENTAL METHODS

INSTRUMENTATION AND PROCEDURES

A prospective cross-sectional study was conducted on patients who had undergone abdominal CR examination at Hospital Raja Permaisuri Bainun (HRPB), Ipoh, Perak with the inclusion of all adult patients (n = 69) age from 20-65 years. Subjects were categorised into normal BMI of 22.9 kg/m^2 and lower (n = 23), overweight of 22.9–30 kg/m^2 (n = 23) and obese of 30 kg/m^2 and above (n = 23). The categorization is made because in general radiography any changes in exposure factors usually occurs categorically based on the patient body size. For instance, in most general x-ray unit using an automatic exposure setting, the icon selection for body size of thin, medium and obese can be found at the control panel. For underweight patient it was considered as normal in this study. Exclusion criteria for this study were patients too ill to lay on supine position, restless, uncooperative and have osteoporosis, Paget's disease as well as ascites. Patients with osteoporosis and Paget's disease were excluded in the experiment because it can alter the SNR reading of the pixel intensity that would give outlier reading. Technical parameters (Table 1**)** used for this abdominal CR examination were in accordance with the recommendation by the Commission of the European Communities (CEC 1996).

All the abdominal CR examinations were conducted after being approved by the ethical council of the Malaysian Ministry of Health (NMRR-15-1427-25397). An explanation was given, and informed consent was obtained from all subjects prior the examination. Height, weight and WC were measured by the researchers before the radiographer on duty performed the examination. BMI was calculated by the researchers on the basis of the BMI index definition as weight in kilograms divided by height in square meters (kg/m^2, WHO).

The x-ray equipment Siemens Multixtop 80 kilowatt generator three-phase high-frequency Polydoros with aluminium filtration of 2.5 mm was used in this study. This unit was fixed with an AEC having three types of ionisation chamber configuration and with a 'microprocessor catapult'. The CR equipment used was a Max Direct view CR system (Carestream Health Inc. USA). Carestream CR cassette plates of size 35 cm × 43 cm having a spatial resolution of 10 pixels/mm was used. This cassette imaging plate uses phosphorus material of granular phosphor technology (BaFBr.Eu^{2+}). The collimation used for the field of view of the abdomen was standardised in all BMI categories on the basis of the anterior abdominal surface of one obese patient. The same CR cassette was used during the study, and quality assurance consistency for the tube output and AEC testing was performed on all equipment before the study.

TABLE 1. Technical parameters used

	Actual parameters
Radiographic device	Grid table
Nominal focal spot value	1
Total filtration	2.5 mm aluminium equivalent
Anti-scatter grid ratio (r)	r = 12:1
Screen film system	CR (Carestream exposure index (EI) mean = 1450)
AEC selection	Chamber selected-central
Exposure time millisecond (ms)	< 400 ms
Image receptor size used	35 cm × 43 cm
Focus film distance	100 cm
Radiographic voltage (kVp)	85 kVp

During the radiographic examination of the abdomen, the anode heel effect must be considered by using the same anode orientation for each examination. The difference in the intensity of x-rays reaches an increase of 20% at the end of the cathode side and a reduction of 25% at the end of the anode side of the x-ray tube (Carlton & Adler 2013). This difference occurs mainly when radiographic examination requires a large image receptor, such as in the abdominal and vertebrae radiographic examinations. In this study, the upper abdomen is positioned towards the anode end, while pelvis towards the cathode end in order to minimise or to exploit the anode heel effect. Upper abdomen includes diaphragm and lower lung in which the tissue density is less than pelvis and technically is recommended to position on the anode side which has less radiation intensity compared to the cathode side.

IMAGE QUALITY

Two image quality parameter methods were used, namely, quantitatively signal to signal to noise (SNR) and qualitatively visual grading analysis (VGA). The literature review emphasised that many studies related to the radiographic image quality have used quantitative measurements, such as SNR with a combination of qualitative assessment of VGA (Neitzel et al. 1994; Tingberg et al. 2004; Mraity et al. 2014). VGA relies on subjective radiographic image assessors, is used to evaluate normal anatomical radiographic images in determining exposure factors. Thus VGA provides an excellent overall image quality evaluation unlike physical image quality assessment methods (Moore et al. 2013).

The VGA scoring of the abdominal CR images in this study were assessed by the radiographers at HRPB with clinical working experience of at least 20 years. Given the researchers' limited study timing, 10 radiographers with the experience eligibility were approached purposely. Only 2 agreed and 8 of them refused to participate in this study and blinding was imposed. VGA scoring on the images was performed by referring to the CEC 1996 abdomen image criteria. A moderate inter-observer agreement in the image quality scores was determined by Cohen's *kappa* coefficient of 0.65 ($p < 0.05$). The radiographers were asked to provide the scoring of the CEC 1996 abdomen criteria by using a five-point scale, in which a score of 5 correspond to excellent visibility; a score of 4 for good visibility; a score of 3 for moderate visibility; a score of 2 for poor visibility; and a score of 1 for an unacceptable image (Reis et al. 2014).

SNR represents the relationship between signal and noise in the image, and SNR is usually taken to indicate the average SNR. SNR was measured by calculating the intensity of the signal (N) mean in a region of interest (ROI) and dividing this by the standard deviation of the signal (Strauss & Rae 2012). In this study, four ROIs on the abdominal CR image at the liver shadow, middle of right and left psoas muscles and at the left iliac bone were chosen. The pixel intensity of these ROIs were investigated using *image J* software, which was downloaded online at (https://imagej.nih.gov/ij/) (Lanca & Silva 2013). The mean values of VGA and SNR of the WC and BMI categories were analysed individually using the appropriate statistical tests.

Data were analysed using SPSS 22 (IBM, New York. USA). Descriptive statistics was inferred from the data, whereas statistical test was conducted for comparison between BMI categories and the image quality with analysis of variance (ANOVA). Any significant difference within the groups on the ANOVA test was followed up with the Post Hoc Tukey test to identify the responsible BMI group. Pearson's correlation was used to determine the relationship between BMI and the image quality with the level of significance ($p < 0.01$).

RESULTS

A total of 69 subjects were used as samples with female and male percentage as shown in Table 2. Table 3 shows the WC in centimetre (cm) ranging from 89.76 ± 14.05 and other patient data of BMI, weight and height for normal, overweight and obese patients of this study.

TABLE 2. Body weight categories according to gender (n = 69)

Body weight categories	Female (%)	Male (%)
Normal	11 (15.94)	12 (17.39)
Overweight	11 (15.94)	12 (17.39)
Obese	9 (13.04)	9 (13.04)

TABLE 3. Mean, standard deviation (SD) values of gender, age, weight and height values according to BMI categories (*n* = 69)

Demographic Factor	BMI categories	Mean ± SD
Age/years	Normal	47.04 ± 10.43
	Overweight	49.87 ± 12.52
	Obese	46.74 ± 11.48
Mass/kg	Normal	52.85 ± 6.41
	Overweight	69.67 ± 7.79
	Obese	76.27 ± 16.93
Height/m	Normal	1.63 ± 0.062
	Overweight	1.65 ± 0.061
	Obese	1.67 ± 0.064
BMI/kgm^{-2}	Normal	19.73 ± 1.52
	Overweight	25.63 ± 1.94
	Obese	34.38 ± 3.59

IMAGE QUALITY AND BMI CATEGORIES

Table 4 presents the mean with SD of SNR and VGA values. Figures 4(a) and (b) show the sample images of abdominal CR with the VGA and SNR score for obese and normal patients in this study. ANOVA test single measure was performed on the SNR and VGA between the BMI categories.

TABLE 4. SNR and VGA values for normal (n = 23), overweight (n = 23) and obese (n = 23) patients

	BMI categories			p-value
	Normal (n = 23)	Overweight (n = 23)	Obese (n = 23)	
SNR (mean ± SD)	60.79±2.19	59.66±1.68	55.78±4.31	<0.01[a]
VGA (mean ± SD)	4.40±0.15	4.35±0.13	4.03 ± 0.34	<0.01[a]

[a] One-way ANOVA

ANOVA test showed there was a significant difference ($p < 0.01$) between the three BMI groups. Further assessment using the Post Hoc Tukey test revealed, for VGA, 2 between groups showed the significant difference, that were between normal and obese ($p = 0.000000515$) as well as between overweight and obese ($p = 0.000112$) categories. For SNR the Post Hoc Tukey showed the same results in the responsible groups.

CORRELATION BETWEEN BMI WITH VGA AND SNR

The relationship of BMI with the image quality of the abdomen examination was determined using Pearson's correlation. In this study, BMI showed a moderate negative linear relationship with the image quality of SNR ($r = -0.73$, $p < 0.01$) and of VGA ($r = -0.70$, $p < 0.01$) in the AP supine projection, whereas WC indicated a moderate to high negative linear relationship with the image quality of SNR ($r = -0.83$, $p < 0.01$), VGA ($r = -0.79$, $p < 0.01$). The scatter plot graphs in Figures 1, 2 and 3 illustrate distinctively the negative linear relationship between WC and BMI on the image quality of SNR and VGA.

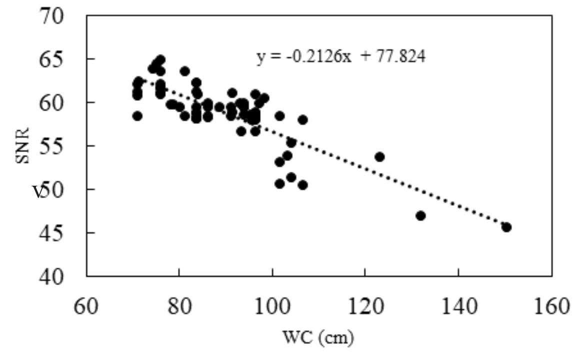


FIGURE 1. SNR value as a function of WC for AP projection

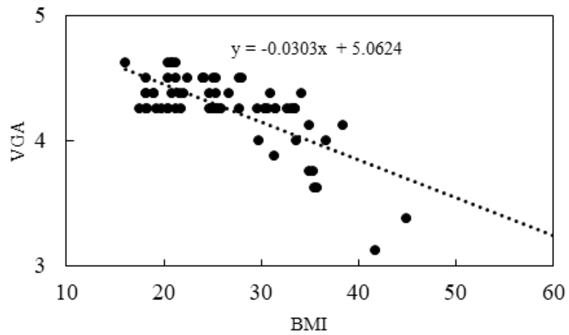


FIGURE 2. VGA value as a function of BMI for AP projection

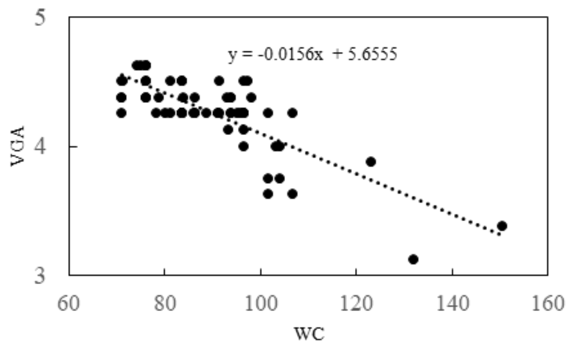
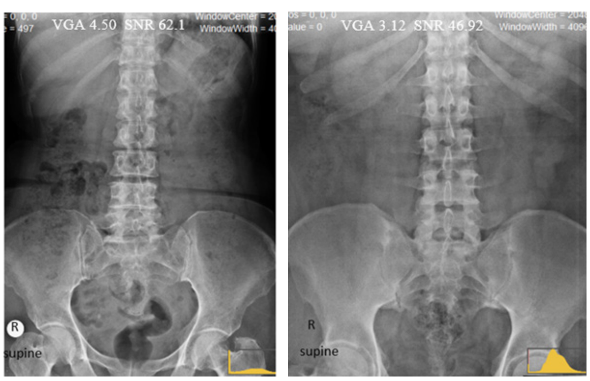


FIGURE 3. VGA value as a function of WC for AP projection



(a) (b)

FIGURE 4. Abdominal CR image of (a) normal BMI with VGA 4.50, SNR 62.1 and (b) obese BMI with VGA 3.12, SNR 46.92

DISCUSSION

Current study clearly demonstrated that the image quality of CR abdomen decreased when BMI (Figure 2) and WC (Figure 3) increased. VGA scores reached less than good visibility as the BMI reached above 35 kg/m^2 and for WC the VGA scores corresponded less than good visibility scores at the WC value of above 100 cm (Figure 3). The degradation of image quality happens primarily due to the Compton scatter. Compton scattering is the major interaction of x-ray photons in the range of diagnostic x-ray energy with soft tissue. As the exposure factor increases in obese patient, the angle of scattered radiation will become narrow. Regardless of with the use of the anti-scatter grid; this narrow angled scatter radiation can escape from being absorbed by the anti-scattering grid and then detected by the image detector as a noise (Holmes et al. 2014). Furthermore the CR detectors cannot distinguish between the scattered and primary radiation and the signal in is directly related to the number of photons hitting on it (Williams et al. 2002). As a result the SNR will be reduced and so does the detective quantum efficiency (DQE) of the imaging system. DQE is related to signal-to-noise ratio (SNR) and modulation transfer function or the system resolution (Bushberg et al. 2002).

Supine position for AP projection is a relatively independent position. The subcutaneous adipose tissue of obese patients in this position falls to both sides of the body. The abdominal anatomy also varies in size and length due to the differences in body habitus because the stomach contains much adipose tissue in obese patients (McQuillen 2015). In relation to WC, additional subcutaneous tissue coupled with visceral fat in the central part, which is called central obesity, is the thickest part amongst the other parts of the abdomen in obese patients (Maurovich-Horvat et al. 2007). This part multiplies the Compton scattering interaction enormously. The effect of scattered radiation resulting from additional tissues or tissue thickness with regard to WC or BMI is measured by the ratio of scattered to primary radiation (Webb & Flower 2012). If the ratio is high, then the radiographic contrast of the image will decrease considerably. For example, the thickness of 20 cm for patients in the lumbar radiographic examination can produce a ratio of scattered to primary radiation of 4.4, and the thickness of 35 cm in other patients can reach 5.7 (Modica et al. 2011).

Contrary to BMI, patients' WC and body weight are more useful for imaging (Uppot et al. 2007). The present study showed that the WC could better predict image quality due to its higher correlation coefficient than that of BMI. WC is suited for body measurements in radiology for obese patients because high WC indicates that patients have a high central obesity, and this condition will produce a more detrimental effect on the image quality than the high BMI without central obesity. As a result, the correlation coefficient of WC in the current study was higher than that of BMI. Furthermore, if WC is high, then the probability of motion artifact will increase and degenerate the image quality.

For medical diagnostic purposes at 60–70 kVp, a wider difference in attenuation occurs by structures of different density than at higher kVp. In other words, the radiographic contrast can be increased using low kVp due to the increase in photoelectric absorption during the interaction of x-ray photons with the body atoms. However, in the present study, the standard kVp of 85 was used for all the subjects to ensure sufficient penetration for even the most obese patient and eliminate the confounding factors of kVp on the results. The findings of a study on the tube voltage effects on the image quality of the chest digital radiography using the flat-panel detectors by categorising BMI patients showed that, at 90, 121 and 150 kVp settings, low BMI groups has higher VGA scores than high BMI groups, which indicates that the BMI category has a direct impact on image quality (Uffmann et al. 2005). A part from kVp, tube current (mA) controls the quantity of radiation; the amount of radiation delivered is the product of mA and exposure time or milliampere seconds (mAs) and affects the noise but not the radiographic contrast (Huda et al. 1996). In the current study, AEC used was of ionisation type and could detect the mAs rather than kVp and control the noise in the CR imaging plate at a minimum level.

Other confounding factors on the results of this study were minimised by necessary controlling steps. The scattered radiation increases as the patient size or thickness increases. Thus, the examination for all the patients was performed with the radiographic table grid of a high ratio of 12:1. Compared with other parts of the body, abdominal CR requires the largest field of x-ray collimation especially for obese patients to cover all the desired field of view. Light field of the collimation for the current obese patients appeared to be very small. Thus, standardisation was made based on one obese patient.

The VGA and SNR values in this study have a strong positive correlation of $R^2 = 0.94$ ($r = 0.97$). This finding is in accordance with that of Mraity et al. (2014), who found that the VGA and SNR have a strong positive correlation of $R^2 = 0.98$ ($r = 0.99$). The current result also agrees well with that of Ullman et al. (2004), who demonstrated that the relationship between VGA and SNR for a simulation study of pelvis image in the AP projection has established a correlation coefficient of $R^2 = 0.94$ ($r = 0.96$).

Figure 2 shows that BMI in the range of less than 35 kg/m^2 is in VGA of good visibility score. As shown in Figure 3, the same score of VGA correspond for WC of less than 100 cm. The radiographer should consider additional steps when performing abdominal CR for BMI of more than 35 kg/m^2 and WC of more than 100 cm as technically obese. In handling obese patients, the kVp and mAs must be increased, grid with high ratio and compression band must be used and alternative projection and collimation must be conducted (Le et al. 2015; Modica et al. 2011). This way minimises repetition of radiography examinations. Studies on the causes of rejected plain x-ray images found that among the reasons are rare use of an exposure chart and failure to measure patient size (Nol et al. 2005).

In the present study, for the body size of the patient, radiographers can use either BMI or WC in estimating the exposure factors. WC is obtained using a measuring tape around the patient's waist, whereas BMI is calculated using the weight and height of the patient. WC can also be estimated as an exposure factor guide by simply inquiring trousers' size of patients. In terms of practicability, WC can be practical for normal and bedridden patients. In the meantime, BMI can be suitable for a normal patient and patients with data of weight and height that can be obtainable.

This study was conducted without considering abdominal pathology. Ascites can lead to under-exposure images due to the fluid accumulation and can be prevented by adding mAs of 30%–50% and kVp value of 5%–8% from the routine projection (McQuillen 2015). The image quality of the selected subjects with this pathology can be investigated in the future.

CONCLUSION

WC and BMI have a negative linear correlation with the SNR and VGA. WC has a correlation coefficient r value greater than that of BMI for the image quality measured. Apart from BMI, this study suggests that WC can also be used as an excellent predictor of image quality in abdominal CR. In clinical setting, WC can be used to estimate the exposure factors for abdominal CR irrespective of patient condition.

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