Study on the Effect of Individual Factors on the Radiation Dose in Chest CT

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Research

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Abstract

Objective

To explore the influence of patient's individual factors on the radiation dose in chest computed tomography (CT) scan.

Methods

Based on the clinical chest CT scan scheme and the scanning conditions were unified, Basic data of 103 patients who underwent chest CT scanning, including gender, age, height, weight and underlying diseases, were prospectively collected, and the dose length product (DLP) of each patient was recorded, Multivariate regression analysis was made on the obtained data.

Results

Under the same scanning parameters, image quality had no significant effect on chest CT radiation dose ($P = 0.404 > 0.05$); among the 103 cases, there were 20 kinds of basic diseases, only calcified lesion has a significant effect on chest CT radiation dose ($P = 0.009 < 0.05$), the other had no significant effects ($P > 0.05$); the major effect individual factors of radiation dose in CT scan were: gender ($P = 0.000003 < 0.05$), age ($P = 0.016 < 0.05$), height ($P = 0.000021 < 0.05$), weight ($P = 4.30E-16 < 0.05$). Age ($P = 8.08E-8 < 0.05$) and weight ($P = 5.52E-21 < 0.05$) were the only decisive factors in multiple regression analysis, while other influencing factors were not decisive ($P > 0.05$). The regression model was as follows: $DLP = -39.45 + 2.19 \times \text{age} + 5.54 \times \text{weight}$, the coefficient of multiple correlation R being 0.786, $F(2,100) = 77.128$, $P < 0.01$. Mean that gradually increase in age was related with 2.19 mGy•cm increase in the DLP value, 1 kg increase in weight was associated with 5.54 mGy•cm increase in the DLP value.

Conclusion

For chest CT, age and weight are the major impact individual factors of radiation dose. This model has shown obvious clinical significance and can provide solid theoretical basis for clinical application in reducing the radiation dose in chest CT.

Background

With the rapid development of medical science and technology, X-ray computed tomography (CT) has been widely used in clinical practice and the low-dose chest CT has become one of the means of lung cancer screening[1–2], but its accompanying radiation problem was also closely watched[3], so how to practice the as low as reasonably achievable (ALARA) principle and reduce the radiation dose has

become the hot topic in the field[4]. In this study, the influence of individual factors on radiation dose was studied.

Results

Research data

The data of 103 patients were collected, including gender, age, height, weight, dose length product (DLP), and the prevalence of 20 basic diseases such as interstitial changes, infection, inflammation, proliferation, fiber, pneumatocele, lung nodules, pleural effusion, lung cancer, mediastinal lymph nodes, atelectasis, pulmonary bullae, emphysema, breast carcinoma, calcified lesion, pulmonary congestion, pleural thickness, bronchiectasis, mosaic perfusion, lung destroyed and so on. There were 51 males and 52 females, aged 27–88 years, 58 ± 14.2 years on average. The baseline data of all patients are summarized in Table 1. For continuous variables, the description method is determined according to whether the data obeys normal distribution or not, if obeys the normal distribution, use the available mean $\pm$ standard deviation (SD); if not obey the normal distribution, use the median (1/4 quartile-3/4 quartile). For the classification variables such as basic diseases, the number of patients and the percentage of the total number of patients are used to describe the data.

Table 1
Baseline data of all patients

Factor	Indicators
Patient (n)	103
Age (years)	58.21 ± 1.40
Height (cm)	162.5 ± 0.78
Weight (Kg)	65 (60-77.2)
DLP (mGy•cm)	404. 3 (359.5-488.5)
Interstitial changes (n [%])	6 [5.8]
Infection (n [%])	5 [4.9]
Inflammation (n [%])	39 [37.9]
Proliferation (n [%])	9 [8.7]
Fiber (n [%])	25 [24.3]
Pneumatocele (n [%])	2 [1.9]
Lung Nodules (n [%])	32 [31.1]
Pleural Effusion (n [%])	4 [3.9]
Lung Cancer (n [%])	5 [4.9]
Mediastinal Lymph Node (n [%])	6 [5.8]
Atelectasis (n [%])	2 [1.9]
Pulmonary Bullae (n [%])	10 [9.7]
Emphysema (n [%])	9 [8.7]
Breast Carcinoma (n [%])	1 [1.0]
Calcified Lesion (n [%])	8 [7.8]
Pulmonary Congestion (n [%])	1 [1.0]
Pleural Thickness (n [%])	6 [5.8]
Bronchiectasis (n [%])	5 [4.9]
Mosaic Perfusion (n [%])	1 [1.0]
Lung Destroyed (n [%])	1 [1.0]

Image Evaluation Results

Image quality assessment ≥ 4 is classified as high-quality image, ≤ 3 is classified as inferior image (Fig. 1). There was no correlation between image quality and chest CT radiation dose ($r=-0.083$, $P = 0.407 > 0.05$). Furthermore, Image quality had no effect on chest CT radiation dose (**Table 2**).

Table 2 Image evaluation statistics

Classification	5	4	3	2	1	DLP
Case	52	38	13	0	0	
Case of high-quality image ≥ 4	90					417.1±77.95
Case of poor-quality image ≤ 3			13			444.0±119.1
The <i>P</i> value of all images	0.404> <i>P</i> =0.05					

Correlation Index Of Dlp

The correlation analysis of DLP with individual factors and underlying diseases are shown in Table 3. The DLP was significantly correlated with gender, height, weight, age and calcified lesion and there was no correlation with interstitial changes, infection, inflammation, proliferation, fiber, pneumatocele, lung nodules, pleural effusion, lung cancer, mediastinal lymph nodes, atelectasis, pulmonary bullae, emphysema, breast carcinoma, pulmonary congestion, pleural thickness, bronchiectasis, mosaic perfusion and lung destroyed (Table 3).

Table 3
Correlation between DLP and respective variables

DLP	Gender	Height	Weight	Age	Interstitial changes	Infection
r	0.431**	0.419**	0.723**	0.238*	-0.137	-0.047
P	0.000003	0.00002	4.3E-16	0.016	0.169	0.637
DLP	Inflammation	Proliferation	Fiber	Pneumatocele	Lung Nodules	Pleural Effusion
r	-0.042	0.126	0.142	0.118	-0.087	-0.071
P	0.671	0.205	0.153	0.234	0.379	0.476
DLP	Lung Cancer	Mediastinal Lymph Node	Atelectasis	Pulmonary Bullae	Emphysema	Breast Carcinoma
r	-0.076	-0.116	-0.088	0.170	0.102	-0.093
P	0.446	0.244	0.379	0.086	0.306	0.349
DLP	Calcified Lesion	Pulmonary Congestion	Pleural Thickness	Bronchiectasis	Mosaic Perfusion	Lung Destroyed
r	-0.26**	-0.103	-0.093	-0.084	-0.153	-0.143
P	0.009	0.299	0.348	0.401	0.122	0.149
Note: ** means $P < 0.01$ (double tail), and the correlation is significant. * means $P < 0.05$ (double tail), and the correlation is significant.						

Further analysis shows that, correlations between the respective variables. there was a correlation between gender and height ($r = 0.628$, $P = 2.22E-10 < 0.01$), weight ($r = 0.416$, $P = 0.00003 < 0.01$), pulmonary bullae ($r = 0.266$, $P = 0.007 < 0.01$). there was a correlation between height and weight ($r = 0.569$, $P = 3.48E-10 < 0.01$), age ($r = 0.203$, $P = 0.039 < 0.05$), pulmonary bullae ($r = 0.276$, $P = 0.005 < 0.01$). there was a correlation between weight and calcified lesion ($r = -0.240$, $P = 0.015 < 0.05$), pleural effusion ($r = -0.234$, $P = 0.018 < 0.05$), proliferation ($r = 0.229$, $P = 0.02 < 0.05$). there was a significant correlation between age and image quality ($r = -0.369$, $P = 0.00013 < 0.01$), emphysema ($r = 0.321$, $P = 0.001 < 0.01$). there was a correlation between inflammation and fiber ($r = 0.255$, $P = 0.009 < 0.01$), bronchiectasis ($r = 0.196$, $P = 0.047 < 0.05$). there was a correlation between lung cancer and mediastinal lymph node ($r = 0.522$, $P = 1.51E-08 < 0.01$), atelectasis ($r = 0.296$, $P = 0.002 < 0.01$), there was a correlation between mediastinal lymph node and bronchiectasis ($r = 0.330$, $P = 0.002 < 0.01$). there was a correlation between atelectasis and emphysema ($r = 0.206$, $P = 0.037 < 0.05$). there was a correlation between calcified lesion and lung destroyed ($r = 0.341$, $P = 0.0004 < 0.01$). there was a correlation between pleural thickness and lung destroyed ($r = 0.398$, $P = 0.00003 < 0.01$). there was a correlation between bronchiectasis and lung destroyed ($r = 0.438$, $P = 0.000004 < 0.01$). there was a correlation between mosaic perfusion and image quality ($r = -0.261$, $P = 0.008 < 0.01$).

Because DLP does not obey normal distribution, Mann-Whitney U test was used to analyze the differences and effects of basic diseases such as gender and interstitial changes on DLP. There was a significant difference between DLP and gender ($P = 0.000013 < 0.01$), and calcified lesion had effect on DLP ($P = 0.01 < 0.05$).

Multiple Regression Analysis

By observing the scatter plots of individual factors (age, height, weight) and DLP of patients, it can be seen that the radiation dose has a good linear relationship with height and weight, and an approximate linear relationship with age (**Fig. 2**).

According to the previous correlation analysis, there was a significant correlation between DLP and sex, height, weight, age and calcification. Furthermore, multivariate stepwise regression analysis was used to investigate the influence of five significantly correlated indexes on DLP. According to the significant results in Table 4, Only weight and age had significant effects on DLP, while other variables had effects on DLP but had no statistical significance.

Table 4
Regression analysis

Variable	Regression Coefficient	Standard Error	<i>t</i>	<i>P</i>	Confidence Interval of Regression Coefficient
Constant term	-39.449	39.259	-1.005	0.317	[-117.3, 38.44]
Weight	5.543	0.464	11.954	5.52E-21	[4.623, 6.463]
Age	2.191	0.378	5.792	8.08E-8	[1.440, 2.941]

Based on Table 4, the regression equation of the influence of individual factors on chest CT radiation dose was established as :

$$\text{DLP} = -39.45 + 5.54 \times \text{Weight} + 2.19 \times \text{Age}$$

Formula 1, the regression equation of DLP depend on individual factors, the radiation dose can be calculated by knowing the body weight and age of the person being examined. The constant of the regression equation is -39.45, the slope of weight is 5.54, that is, the DLP increases by 5.543 for every 1 kg of weight; the slope of age is 2.19, that is, the DLP increases by 5.543 for every 1 year increase (In this equation, the unit of weight is: kg; the unit of age is: year).

Next, the fitting degree of the regression model will be illustrated by the multiple correlation coefficient R value, variation degree variable R^2 and analysis of variance table. Regression model statistics show that the value of index R is 0.779 indicates the regression model has medium-high correlation, the value of adjusted R^2 is 0.599 indicates the regression model has high influence intensity, and the Durbin-Watson test value is 2.058, which further indicates that the observed indicators are related and independent (Table 5). Variance analysis of regression model shows that the regression model has statistical significance, $F(2,100) = 77.128$, $P = 5.45E-21 < 0.01$, suggesting that there is a linear correlation between dependent variables and independent variables. It also further shows that the effects of the two indicators included in the model on DLP are statistically significant (Table 6).

Table 5
Regression model statistics

R	R^2	Adjusted R^2	Error of standard estimation	Durbin-Watson
0.779	0.607	0.599	53.18535	2.058

Table 6
Variance analysis of regression model

Model	Quadratic sum	DOF	Mean square	F	P
Regression	436341.453	2	218170.726	77.128	5.45E-21
Residual	282868.184	100	2828.682		
Sum total	719209.637	102			

Discussion

Since the clinical application of spiral CT, the radiation dose of CT is high, accounting for about 1/2 of the total medical radiation exposure [5]. Therefore, low-dose CT scanning has been the focus of clinical and scientific research [6]. Previous studies have explored the factors affecting the radiation dose of patients from the aspects of scanning methods and reconstruction methods, but have not discussed the factors affecting the radiation dose from the factors of the patients themselves.

In the early stage, the scanning radiation dose was reduced mainly by reducing the tube current, tube voltage, reducing the scanning time and applying automatic tube current modulation technology (auto mA) [7]. Some researchers [8–12] believe that the image quality can meet the diagnostic requirements when the dose is 40mAs. Zhang [8–9] reduces radiation dose through tube voltage, detector width and pitch combined with organ dose modulation technology. Song [10] found that the dose of some models of spiral CT is inversely proportional to the pitch when the tube current is constant, while some models adopt the technology of automatically adjusting tube current, and the radiation dose remains unchanged when the pitch changes. Of course, the matching of detector and pitch not only affects the volume coverage and image quality, but also affects the radiation dose to a certain extent [11–12].

In terms of reconstruction method, excessive reduction of radiation dose will lead to insufficient data acquisition and increased noise in filtered back projection (FBP) reconstruction, which will result in image quality not meeting the needs of diagnosis [13]. Model-based iterative reconstruction (MBIR) is an iterative algorithm based on original data, and a new generation of model-based iterative reconstruction (the new version of MBIR, MBIRn), which has unique advantages in reducing X-ray radiation dose and improving image quality [14]. Iterative reconstruction (IR) is to improve image quality and reduce image noise and artifacts through many iterations at lower radiation dose [15]. Adaptive statistical iterative reconstruction (ASIR) is based on the system statistical model, and its clinical application value has been confirmed [16–17]. when the iterative intensity of conventional chest CT plain scan ASIR is set at 40%-60%, the image quality noise and contrast noise are higher, the lung window and mediastinal window score is the highest [18], while the image quality is guaranteed, the radiation dose is significantly reduced [19].

In 2015, the World Health Organization determined that the body mass index (BMI) of normal adults was 18.5–24.9 kg/m². BMI $\geq$ 25.0 kg/m² was obese, and BMI < 18.5 kg/m² was emaciated. Qin [20] conducted a low-dose chest scan study using 256 iCT according to this grouping standard, which only revealed that this grouping was beneficial to reducing radiation dose. Other domestic researchers [21–23] also studied the reduction of radiation dose based on body mass, but did not explain the relationship between body mass and radiation dose. Saade et al. [24] divides people according to their different body weight into four grades, $\leq$ 60, 60–80, 81–100 and $\geq$ 101 kg, to study the effect of body weight and radiation dose. It was found that there was a certain relationship between body weight and radiation dose. As the body weight of Chinese population is generally lower than that of European and American people [25], Chen et al. [26] divides people with a body weight of 60 kg into two groups: $\leq$ 60 kg and > 60 kg. Different scanning parameters are selected respectively, and it is also found that body weight can affect the dose of CT radiation. This study shows that body weight not only affects the radiation dose, but also reveals that there is a positive correlation between individual radiation dose and body weight, the slope is 5.54, that is, each increase in body weight of 1 kg, DLP will increase 5.54 mGy•cm (**regression equation 8**). Although there was a significant correlation between height and DLP ($P = 0.00002 < 0.01$, see Table 3), the multiple regression analysis showed that it had no significant effect on DLP ($P = 0.917 > 0.05$).

In radiological dosimetry, the difference of individual response to ionizing radiation is the key factor affecting the accurate estimation of biological dose. Studies have shown that individual differences in gene expression are mainly related to gender, age, smoking, lifestyle and inflammatory response [27–29]. The results of Li [30] showed that the relative expression level of mRNA of most genes in peripheral blood of female irradiated in vitro was higher than that of male, indicating that the radio sensitivity of women was higher than that of men. This study also showed that there was a very significant correlation between gender and DLP ($P = 0.000003 < 0.01$ (Table 3)), and there was a very significant difference between gender and DLP ($P = 0.000013 < 0.01$). However, in the regression analysis, the effect of gender on DLP was not statistically significant ($P = 0.177 > 0.05$). The main reason may be that there was a strong correlation between sex and height ($r = 0.416$, $P = 0.00003 < 0.01$). The expression of FDXR gene is

most affected by age. When Kajimura et al. [31] conducted cluster analysis on the number of dicentric cells and the expression level of related genes mRNA in 229 Japanese primary explosive population, it was found that both of them decreased with age, suggesting that the age of the recipients may affect the changes of radiation-induced gene expression, but its molecular mechanism remains to be further studied. The results show that the number of bicentric cells and the mRNA expression level of related genes decrease with the increase of age, suggesting that the age of the recipients may affect the changes of gene expression induced by radiation, but its molecular mechanism remains to be further studied. This study shows that there is not only a significant correlation between age and DLP ($P = 0.016 < 0.05$ (Table 3)), but also a main influencing factor in the establishment of regression equation ($P = 8.08E < 0.01$ (Table 4)). It also reveals that there is a positive correlation between individual radiation dose and age, the slope is 2.19, that is, gradually increase in age was related with 2.19mGy•cm increase in the DLP value (**regression equation 8**).

In general, the radiation dose assessment parameters of CT scanning are volume CT dose index (CTD_{vol}) and DLP [32–34]. The effective radiation dose (ED) of the patient can be calculated by the formula: $ED = DLP \times k$ (chest conversion coefficient, $k = 0.014 \text{ mSv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$) [35]. Their consistency is good [36]. CTD_{vol} will underestimate the radiation dose received by the patient, and the smaller the BMI, the greater the underestimated dose value [37]. In 2014, the American Society of Medical physicists proposed the method of body type-specific dose estimation (size specific dose estimation, SSDE) [38], which uses the water equivalent diameter (Dw) to estimate SSDE. SSDE refers to the estimated CT dose accepted by the patient after body size correction, which is based on the volume CT dose index CTD_{vol} displayed on the CT interface. Compared with CTD_{vol} and DLP assessment methods, SSDE is relatively accurate, but there is still a certain gap between the estimated value of SSDE and the true value of radiation exposure of patients. Based on this, this paper chooses the DLP value which is easy to obtain directly instead of SSDE value as the index of radiation dose, which may be the deficiency of this study.

Conclusions

Through the analysis of the influence of individual factors on chest CT radiation dose, the regression equation of individual factors affecting chest radiation dose is established: $DLP = -39.45 + 5.54 \cdot \text{Wight} + 2.19 \cdot \text{Age}$. The regression equation establishes a theoretical model for reducing the radiation dose of chest CT. According to the model, the radiation dose is reduced based on the individual factors and combined with a variety of scanning parameters, which will be the focus of the next research. It will also bring important guiding significance to clinical work.

Materials And Methods

General Information

Basic data of 103 patients, including age, gender, height, weight and radiation dose were prospectively collected. There were 51 males and 52 females, aged 27-88 years, 58 ± 14.2 years on average. Inclusion

criteria: only single-site chest CT scan of adult patients were included. Exclusion criteria: multi-site chest CT scan, emergency and minor (≤ 18 years old) patients. This study was approved by the hospital ethics committee, and all enrolled patients signed the informed consent.

Scan Methods

GE spiral VCT scanner was used. The patients were required to raise their hands and place them on the top of their head, scan ranged from the thoracic entrance to the lower lung, including the entire lung field. Scan conditions, *120kV tube voltage*, auto-milliampere technique, 100-400mA, 0.5s/r rotation speed, 0.984:1 pitch, 5 mm scan slice thickness, 5mm scan slice gap, 1.25 mm reconstruction slice thickness, 1mm reconstruction slice gap, totally 65 slice, data is automatically uploaded to GE AW4.6 workstation and PACS server after scan. DLP was used to evaluate the total radiation dose received by subjects after a CT exposure scan. $DLP = CTDI_{vol} \times L$, $CTDI_{vol}$ is the volume CT dose index of multi-slice spiral CT scanning, and L is the scanning length along the Z axis.

Image Evaluation

Chest CT images which met the inclusion criteria were evaluated for image quality to assess if the image quality would affect the chest radiation dose. Blind evaluation of image quality was conducted by 3 senior attending physicians and above, and the overall image quality was rated by 5 levels: 5 point, anatomical details distinctly displayed and can be easily evaluated; 4 point, anatomical details clearly displayed and able to evaluate; 3 point, most of the anatomical structures can be used for diagnosis, and a few anatomical structures (diaphragm, bronchial fine grading, etc.) cannot be evaluated; 2 point, basic anatomical structure is not clear and details are not enough to be found; 1 point, anatomical structure is fuzzy and cannot be used for diagnosis [39].

Data Processing

IBM SPSS Statistics 23.0 was used for statistical analysis. Pearson correlation analysis was used to analyze the correlation between DLP and height and age, and Spearman rank correlation analysis was used to analyze the correlation with sex, weight, underlying diseases and image quality. Mann-Whitney U test was used to analyze the differences between DLP and gender, image quality and underlying diseases. The effect of radiation dose was analyzed by multivariate stepwise regression analysis. $P < 0.05$ means the difference had statistical significance. (*, $P < 0.05$ was statistically significant, and **, $P < 0.01$ was extremely significant.)

Abbreviations

CT: computed tomography; ALARA: as low as reasonably achievable; DLP: dose length product; SD: standard deviation; FBP: filtered back projection; MBIR: model-based iterative reconstruction; MBIRn: the new version of MBIR; IR: iterative reconstruction; ASIR: adaptive statistical iterative reconstruction;

BMI:body mass index; CTD_{IVol}:volume CT dose index; ED:effective radiation dose; SSDE:size specific dose estimation; Dw:water equivalent diameter.

Declarations

Ethics approval and consent to participate

Human subjects Experimental protocols were approval by the local ethics committee of the Traditional Chinese Medicine Hospital. Written informed consent was obtained from the patient before screening.

Consent for publication

Not applicable.

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article.

Competing interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Authors' contributions

DZ conceived and designed the study. XL and QL performed the image scan. RL and YC performed the data collection and collation. TY performed the data processing. LL, XL and HY performed image quality evaluation. LF completed statistical analysis. DZ, LF, HY and GW wrote the paper. All authors read and approved the final manuscript.

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Figures

Figure 1

Image Evaluation. a 85 years old, disturbance of consciousness, poor breath holding, bronchial tube truncated artifact (red arrow), classified as poor-quality image. b 75 years old, good breath holding, classified as high-quality image. c 78 years old, suffer from inflammation, poor breath holding, bronchial tube truncated artifact (red arrow), classified as poor-quality image. d 50 years old, suffer from inflammation, good breath holding, classified as high-quality image.

Figure 2

Scatter plot of individual factors and radiation dose (DLP). a Scatter plot of the age and the DLP. b Scatter plot of the height and the DLP, which has a good linear relationship. c Scatter plot of the weight and the DLP, which has a good linear relationship.