Comparison of dose length product and image quality of a biphasic whole-body polytrauma CT protocol with and without the automatic tube voltage selection

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Background and Aims. A significant source of man-made radiation is now linked to medical devices especially X-ray imaging based ones like CT scans which expose the body to cumulative ionizing radiation and thus attendant cancer risks. The aim of this study was to determine whether using a combination of Automatic Tube Current Modulation (ATCM) and Automatic Tube Voltage Selection (ATVS) during two-phase whole-body CT (2PWBCT) examinations would reduce the radiation dose while preserving the image quality.

Patients and Methods. This was a prospective, observational, single-centre study of 127 adult patients who had undergone the 2PWBCT polytraumatic protocol. All were examined on a Somatom Drive scanner (Siemens). The patients were divided into two groups: ATCM only (42 patients) and ATCM +ATVS (85 patients). Patients' arm positions during examination and the examination dose length product (DLP) values were recorded, as well the standard deviations (SD) of the density in reference areas on CT scans for the image quality assessment. The DLP values and image quality in the groups were compared using ANOVA.

Results. Mean Total DLP (in mGy*cm): ATCM only: 3337 +/-797, ATCM+ATVS: 3402 +/-830; P=0.674. No effect of arm position (P=0.586). Mean density SD values in reference areas (in HU) in ATCM only: 49 +/-45, 15 +/-6, 9 +/-2, 12 +/-4, 10 +/-3, in ATCM+ATVS: 48 +/-45, 17 +/-6, 11 +/-3, 15 +/-6, 12 +/-4. SD values was higher in ATCM+ATVS group (P<0.001).

Conclusion. Combination of ATVS and ATCM in polytraumatic 2PWBCT leads to no significant radiation load reduction compared with ATCM only but does lead to a slight degradation of image quality. The radiation load is significantly reduced if the patient has their arms behind the head when scanning, regardless of the activation of ATVS.

Key words: whole body CT, polytrauma, automatic tube current modulation, automatic tube voltage selection, dose length product

Received: October 26, 2023; Revised: December 27, 2023; Accepted: February 15, 2024; Available online: March 4, 2024
https://doi.org/10.5507/bp.2024.004

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INTRODUCTION

The source of the radiation load of the Earth's inhabitants is mainly from the natural background, and a smaller part of the load comes from artificial sources. In developed countries, this ratio is approximately 75% to 25%. The largest source of artificial radiation is medical radiation, which is dominated by X-ray imaging methods[1]. The issue of radiation exposure of the population from medical sources was dealt with in the report of the European Commission on radiation protection No. 154 of 2008 (ref.[2]). The report states that the radiation burden from interventional procedures and computed tomography (CT) is increasing. CT scans account for approximately 57% of the population radiation dose from medical imaging sources, making it the most significant source of medical radiation[3]. With the number of CT scans and their share in the population dose, their effect on the occurrence of malignancies in the population is already measurable[4-6]. For example, in the USA, radiation from CT examinations is responsible for up to 2% of malignancies[6].

However, the radiation exposure from CT scans is not constant and varies depending on several factors, e.g., body habitus, examined area, examination protocol, setting of individual scanning parameters[7]. The effective dose is further increased when using multiphase protocols and when examining multiple parts of the body. A representative of such a protocol is a multiphase whole-body CT scan of patients with suspected polytrauma[8]. A whole-body CT (WBCT) covers the head, neck, chest, abdomen and pelvis up to the region of the greater trochanters. Using a two-phase protocol, the head is examined natively, the arterial phase includes the region from the base of the skull to the greater trochanters, and the venous phase begins at the diaphragmatic dome and ends at the greater trochanters[8]. The effective dose of this examination is estimated to be around 30 mSv (ref.[9]). If the examination is performed using the split bolus technique of contrast agent administration, only one postcontrast phase is performed and the effective dose is reduced to a value of around 20 mSv (ref.[9]). We consider the optimization of the dose in a polytraumatic CT protocol to be very important, as trauma often affects younger radiosensitive individuals, in whom additional CT follow-ups are often necessary, and the risks associated with irradiation are therefore not negligible[10].

In our study, we focused on the possibility of reducing the radiation load of the two-phase WBCT examination by using a combination of two automatic functions: Automatic Tube Voltage Selection (ATVS) and Automatic Tube Current Modulation (ATCM). Both functions are designed to reduce the radiation dose to the lowest level that is sufficient to achieve user-defined image quality.

In ATVS the principle of dose reduction is in an automatic selection of the lowest available voltage on the X-ray tube (based on information about the patient's habitus obtained from the scout view) sufficient enough to achieve the user-defined image quality.

The ATCM algorithm modulates the current on the X-ray tube. The software takes into account the density of the irradiated tissue not only according to the total mass of the scanned volume based on the scout view, but also the different density of the tissue mass in different positions of the X-ray tube during the each single scan.

We hypothesized that using the combination of ATCM and ATVS in a two-phase polytraumatic WBCT protocol reduces radiation exposure without worsening the image quality.

MATERIALS AND METHODS

Study design and patient selection

The study was designed as prospective, observational and single center. The study was approved by local Ethical Committee, an informed consent was waived by the Ethical Committee.

All patients who underwent a two-phase CT polytraumatic protocol in the period from March 2021 to July 2021 were included in the study. The patients were divided into two groups: ATCM only and ATCM+ATVS (see below). Patients with alloplastic materials in their body were excluded; therefore, the results of the study would be probably affected using Iterative Metal Artifact Reduction (IMAR) during CT scanning. All high-density objects (infusion pumps, breathing apparatus, mobile phones etc.) were removed from the scanned area according to our standard routine before the examination.

Technique of CT exam and CT study protocols

All patients were examined using a multidetector dual source Somatom Drive scanner (Siemens Healthineers, Erlangen, Germany). Our institutional standard CT polytraumatic protocol consisted of the following:

- Non-enhanced CT (NECT) covering the neck and C spine from the shoulders to the vertex – tube voltage 120kV, quality reference mAs 147, automatic tube current modulation (Care Dose 4D) on, rotation time 1 s, primary reconstruction slice thickness/increment: 3 mm/3 mm, soft tissue and bone reconstruction filter, multiplanar reconstruction/increment slice thickness; iterative reconstructions were used.
- Contrast enhanced CT scan of neck, thorax, abdomen and pelvis in arterial and portal phase – quality reference mAs 147, automatic tube current modulation (Care Dose 4D) on, rotation time 0.5 sec., primary reconstruction slice thickness/increment: 3 mm/3 mm, soft tissue reconstruction filter, multiplanar reconstruction increment/slice thickness 3 mm/3 mm. Iterative reconstructions were used. An iodinated contrast agent of a dose 1–1.5 mL/kg with a concentration of 400 mg/mL was applied by power injector with a flow of 3.5 mL/s followed by saline flush.
- Tube voltage in the first group of studied patients was 120 kV for all phases (ATCM only, see below). In the second group of studied patients the default value of 120 kV was used only for the head and neck native phase. For artery and venous phase, the function of ATVS was activated (ATCM+ATVS group).
- To divide the patients into groups, we decided to examine patients with ATCM only on even days and with both ATCM and ATVS on odd days during the first three months, in the last two months the combination ATCM + ATVS was mandatory for all patients.

Dose length product assessment

To evaluate the level of radiation exposure we chose dose length product (DLP), which can be used for an approximate calculation of effective doses. In our work we did not calculate the effective dose alone, nor the organ doses. For all patients we used the DLP value provided by the CT device, which is included in the automatically generated protocol available for each CT scan. We noted the DLP value of the entire examination (Total DLP) as well as the values for the arterial and venous phase (Arterial DLP and Venous DLP).

Image quality evaluations

We used the standard deviations (SD) of the density reference areas on axial scans to assess image quality. The reference areas were as follows:

- Trachea (level of the third thoracic vertebra)
- Right sided paravertebral muscles (level of the third thoracic vertebra)
- Liver parenchyma (segment 5)
- Right sided iliopsoas muscle (level of the first sacral vertebra)
- Right sided obturator internus muscle (near pubic bone)

The Region of Interest (ROI) was circular and covered most of the area of the measured structure; to measure the density in liver parenchyma, we used a 2 cm^2 ROI. In patients with an endotracheal tube, we placed the ROI between the tube and the dorsal wall of trachea. We used the venous phase to measure the density values, except for measurements in the trachea and paravertebral muscles, where we used the arterial phase because of the protocol we applied. See also Fig. 4 and Fig. 5 for illustration.

Statistical analysis

We used analysis of variance to assess the differences in Total DLP values between our two groups. Specifically, we analyzed both the DLP values of the arterial phase and the venous phase in both groups. To evaluate image quality, we log-transformed the SD of the density of the reference areas and analyzed the influence of place and group using analysis of variance. For all analyses, we reported the Bayes factors further indicating the strength of evidence in favor of the null and alternative hypothesis. We used the threshold P=0.05 for statistical significance. The analyses were performed in R, the Bayes factors were calculated using the Bayes Factor package.

RESULTS

Patients selection

During the study period 127 patients (age 19–82 years, mean age (MA) 47 years, standard deviation (SD) 18 years) were included: 32 women and 95 men. The ATCM only group consisted of 42 patients (age 19–83 years, MA 47 years, SD 18 years): 13 women (MA 40 years, SD 18 years), 29 men (MA 50 years, SD 17 years). The ATCM +ATVS group consisted of 85 patients (age 20–91 years, MA 48 years, SD 18 years), 19 women (MA 48 years, SD 16 years), 66 men (MA 48 years, SD 19 years).

Patients from both groups, who were in a poor condition and could not be examined with arms placed behind their head were assigned to separate groups; there were 10 such patients in the ATCM only group and 19 patients in the ATCM +ATVS group.

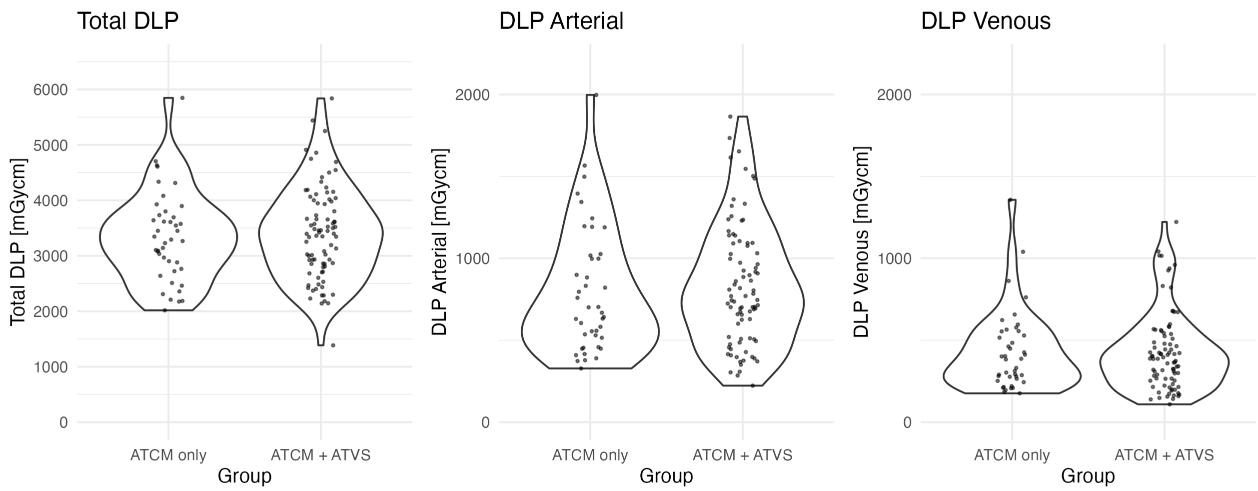

Fig. 1. Total, arterial phase and venous phase DLP values in each group.

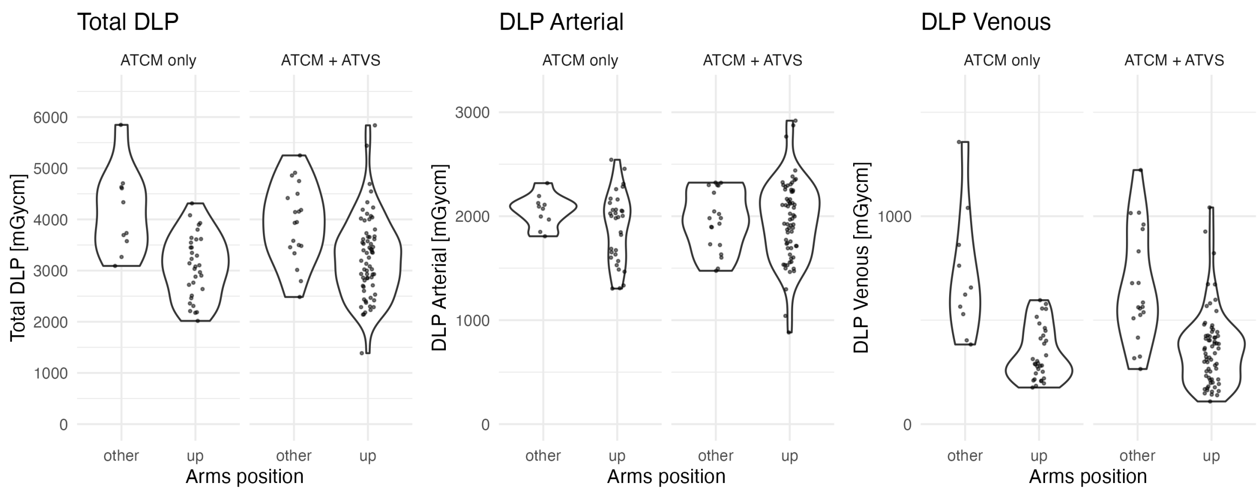

Fig. 2. Total, arterial phase and venous phase DLP values in each group in different arms position.

Radiation doses according to the used dose reduction and arm position

We found no statistically significant differences in Total DLP (Fig. 1) between the two groups ($F(1.125)=0.178$, $P=0.674$; $BF_{10}=0.217$). Similarly, we analysed the DLP values in the arterial and venous phase (Fig. 1). The analysis did not show any statistically significant differences in the achieved DLP values here either (for the arterial phase $F(1.125)=0.198$, $P=0.657$, $BF_{10}=0.219$; for the venous phase $F(1.125)<0.001$; $P=0.999$, $BF_{10}=0.200$). Bayes factor values provided anecdotal to moderate evidence for no difference in Total DLP values between the two groups, neither in the arterial or venous phase. This suggests that the observed lack of difference is not caused solely by small sample size or low statistical power.

Patients examined with arms placed behind their head had lower Total DLP values ($F(1.123)=26.00$, $P<.001$, $\eta_g^2=0.\ 174$, $BF_{10}=11136$), see Fig. 2. There was no significant difference between the two groups in this comparison, nor in the interaction of group and arm position ($F(1.123)=0.298$, $P=0.586$; $BF_{10}=0.217$; interaction: $F(1.123)=1.31$; $P=0.255$; $BF_{10}=1134$). Thus, arms position had the same effect on DLP values regardless of ATVS use. We obtained similar results when evaluating the DLP for the arterial and venous phase (Fig. 2); arms position had an effect on DLP values (for the arterial phase $F(1.123)=36.25$; $P<0.001$; $\eta_g^2=0.228$; for the venous phase $F(1.123)=59.58$; $P<0.001$; $\eta_g^2=0.326$) and there was no significant difference between the two groups, nor in the interaction of group and arm position ($P>0.300$).

Image quality

As expected, SD values varied by area ($F(4.500)=158.28$; $P<0.001$; $\eta_g^2=0.504$), for more details see Fig. 3. We found significantly higher SD values of reference areas in ATCM+ATVS group ($F(1.125)=19.22$; $P<0.001$; $\eta_g^2=0.029$) (Fig. 3), no interaction was found between the area and group ($F(4.500)=0.71$; $P=0.586$).

DISCUSSION

We planned our research project with the aim of proving that the usage of combination ATCM and ATVS in a two-phase polytraumatic WBCT protocol reduces radiation exposure or at least image noise in areas sensitive to underexposure, such as the shoulders or pelvis. Ideally we hoped to prove both intended effects. The results show that neither of the initial theses was confirmed. The radiation burden of both groups of patients, assessed indirectly by the DLP value, was not significantly different statistically. The noise level, roughly assessed by the value of the standard deviation of the density of the reference areas, was slightly, but statistically significantly higher in the group with ATCM+ATVS combination. This applies both to the comparison of both protocols as a whole and to the comparison of their individual phases. The results indicated a significant difference in the DLP value when examining with the arms extended behind the head, compared to the arms positioned at least partly in the examined trunk's volume. Because the position of the upper limbs in the scanned volume of the trunk is non-standard (among others because of a higher number of different ar-

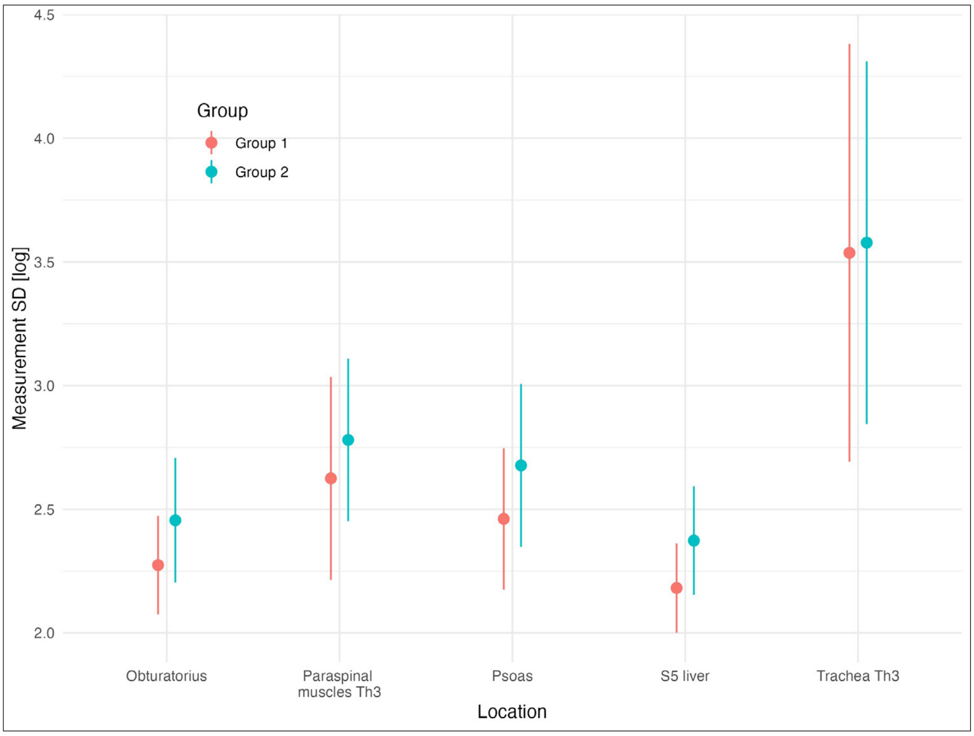

Fig. 3. Density SD in reference areas in each group.

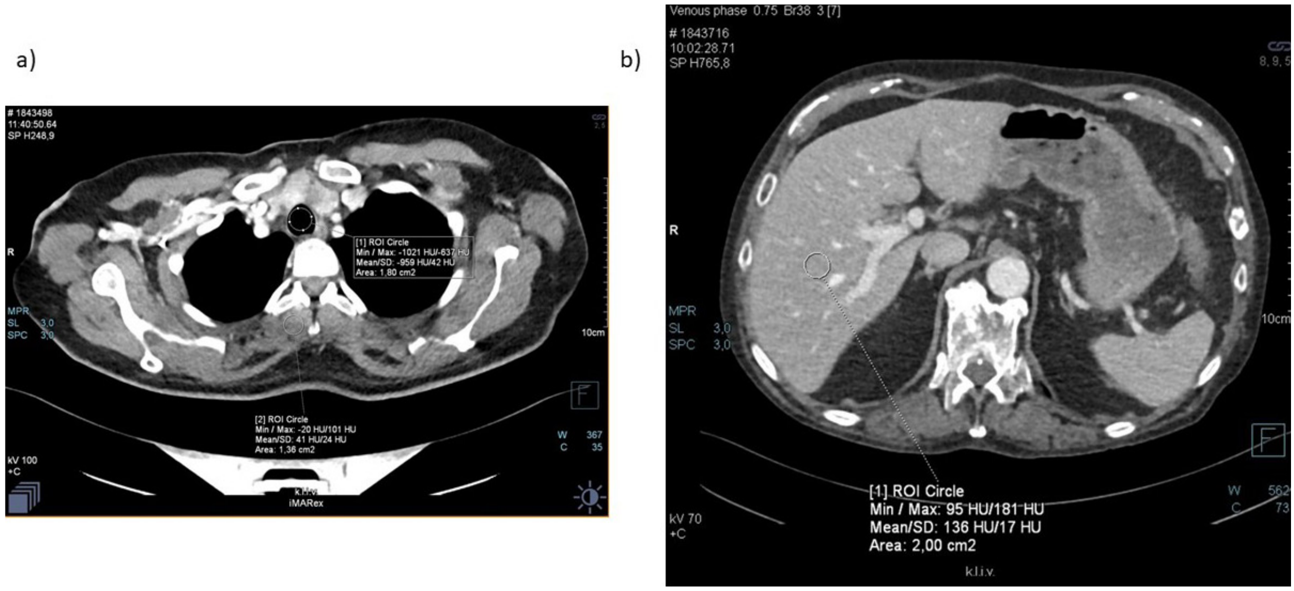

Fig. 4. Density measurement in reference areas: a) trachea and paraspinal muscles, b) liver segment 5.

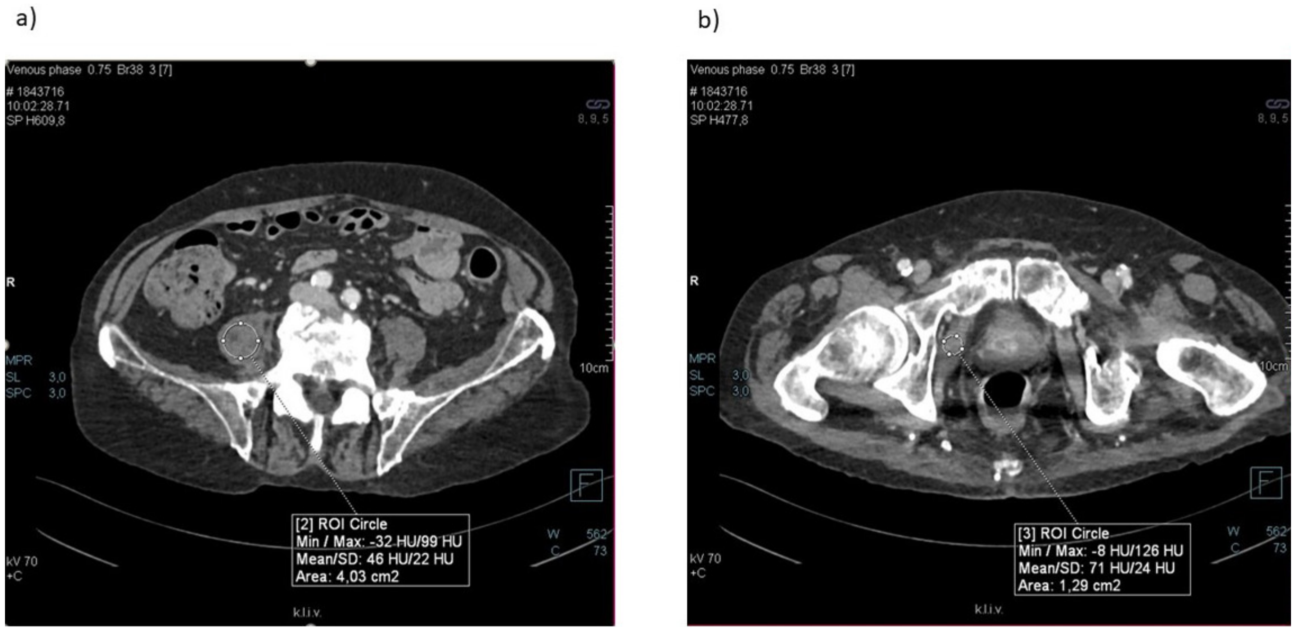

Fig. 5. Density measurement in reference areas: a) musculus psoas, b) musculus obturatorius internus.

tifacts), there is only a relatively small number of patients examined in such a manner in our samples (only patients with obvious or already known trauma of the upper limbs at the time of examination).

The literature mentions the combination of ATVS and ATCM as a suitable way to reduce the radiation load while maintaining sufficient or even achieving higher image quality[11-13]. In the work of Peijie et al.[13], the combination of ATVS and ATCM was supplemented using iterative reconstructions further reducing the level of image noise. None of the reported works compared the effect of using a combination of ATVS and ATCM in a polytraumatic WBCT protocol. However, even if we compared the impact of this combination in only one of the phases of the two-phase protocol, we would reach the examination range investigated by Mayer et al., i.e., for a CT scan of the chest and abdomen[11]. Other cited works focused on the detection of small foci of hepatocellular carcinoma in the liver or the examinations of the liver were limited only to the abdominal area but used a three-phase or even a four-phase protocol[12,13]. These are relatively extensive CT protocols, and the number of scans was comparable to our two-phase polytraumatic protocol. Thus, our different results cannot be explained by completely different methods or a different extent of scanning.

In our study, we did not consider the influence of the patient's habit expressed by the Body Mass Index (BMI) value on radiation exposure and image quality. However, the literature is ambiguous in evaluating the effect of BMI on ATVS function. According to Peijie et al. when using ATVS, the most common voltage value on the x-ray, when examining patients across all BMI groups, was 100 kV.

The value of 80 kV was used particularly in patients with a normal BMI or in underweight patients[13]. In contrast, Lee and co-authors state that the value of 80 kV was chosen by the system mainly in patients with a normal BMI or in overweight patients, while the value of 100 kV was used mainly in underweight patients[12]. This discrepancy is explained by the authors of another study as a possible impact of the small number of patients in their study group[13]. The influence of BMI and the use of the ATVS protocol were relatively thoroughly investigated by Lee et al., who looked at the use of a combination of ATVS and ATCM in CT coronary angiography of obese patients compared to a fixed voltage setting of 120 kV and a current according to BMI of 380 and 450 mAs, respectively[14]. They stated that by using a combination of ATVS and ATCM, they achieved neither a reduction in radiation load nor an improvement in image quality. The results of our study are therefore probably not explainable by the habits of the examined patients.

Another factor that can affect the automatic setting of scanning parameters is the occurrence of high-density objects on the scout view. Even in this aspect, however, our groups of patients did not differ from each other in any way. We did not detect any high-density objects such as infusion pumps, breathing apparatus, mobile phones, monitors and the like on the scout views. The most common foreign objects were ECG electrodes or a pulse oximeter cable, i.e., objects common in seriously ill patients and proportionally represented in both groups.

Our work showed that the use of a combination of ATVS and ATCM when using a two-phase polytrauma CT protocol and when using iterative reconstructions does not affect the radiation exposure of patients, but slightly reduces the quality of the image data. On the other hand, our results indicate that positioning the upper limbs outside the scanned area of the trunk, if possible due to the patient's condition, is of considerable importance for the reduction of radiation exposure. The discrepancy compared to most previous studies could perhaps be explained by the relatively small number of examined patients, and it would certainly be good to expand this research to more institutions in the future.

Our study has significant limitations particularly in the relatively small and uneven number of patients in individual groups. In addition, the results are based on examinations from only one particular CT scanner and its software settings. It would also be beneficial to determine the amount of image noise by more accurate measurements.

CONCLUSION

When using a combination of ATCM and ATVS during a WBCT polytraumatic protocol on a Siemens Somatom Drive CT scanner there was no significant reduction in radiation load, but there was a slight degradation of image quality. To reduce the radiation load, the position of the arms was more important. The radiation load was significantly lower with the arms positioned behind the head.

ABBREVIATIONS

WBCT, Whole body CT; 2PWBCT, Two-phase whole-body CT; ATCM, Automatic tube current modulation; ATVS, Automatic tube voltage selection; DLP, Dose length product.

Acknowledgements: I would like to thank all my collaborators for their cooperation on the research project. I would like to thank Dr. Weichet for his valuable advice on setting the scanning parameters of the CT unit. I would also like to thank the other colleagues of our clinic for the support we received during the work on our research project.

Author contributions: DG: manuscript writing and literature search; KK: manuscript revision JL: statistical analysis; LS: radiation load assessment; HM: head of the clinic and main consultant of the research project

Conflict of interest statement: The authors state that there are no conflicts of interest regarding the publication of this article.

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