Cumulative doses analysis in young trauma patients: a single-centre experience

Sergio Salerno¹ · Maurizio Marrale² · Claudia Geraci¹ · Giuseppe Caruso¹ · Giuseppe Lo Re¹ · Antonio Lo Casto¹ · Massimo Midiri¹

Abstract Multidetector computed tomography (MDCT) represents the main source of radiation exposure in trauma patients. The radiation exposure of young patients is a matter of considerable medical concern due to possible long-term effects. Multiple MDCT studies have been observed in the young trauma population with an increase in radiation exposure. We have identified 249 young adult patients (178 men and 71 women; age range 14–40 years) who had received more than one MDCT study between June 2010 and June 2014. According to the International Commission on Radiological Protection publication, we have calculated the cumulative organ dose tissue-weighting factors by using CT-EXPO software®. We have observed a mean cumulative dose of about 27 mSv (range from 3 to 297 mSv). The distribution analysis is characterised by low effective dose, below 20 mSv, in the majority of the patients. However, in 29 patients, the effective dose was found to be higher than 20 mSv. Dose distribution for the various organs analysed (breasts, ovaries, testicles, heart and eye lenses) shows an intense peak for lower doses, but in some cases high doses were recorded. Even though cumulative doses may have long-term effects, which are still under debate, high doses are observed in this specific group of young patients.

Keywords MDCT · Effective dose · Adsorbed dose · Tissue-weighting factors · Cumulative doses

Introduction

Multidetector computed tomography (MDCT) is increasingly used in trauma imaging due to its efficiency as a diagnostic tool, providing simultaneously speed, high resolution and large body coverage for diagnostic evaluation of emergency patients [1]. The widely diffused use of MDCT for different clinical purpose, however, increases patient and population radiation exposures [2]. Different concerns are consequently emerging about appropriateness, resource utilisation and possible biological costs in terms of radiation exposure. MDCT represents actually the main source of radiation in trauma patients also because patients are referred to hospital for serious injuries and in a short period of time are usually submitted to multiple MDCT examinations for initial diagnosis, follow-up and eventual surgical complications [3].

In emergency care, MDCT has certainly transformed patient’s management and its use is in constant growth; in Italy, at least 2 millions of examinations (29.9 %) were recorded in 2009 in accident emergency (A&E) department on 6 millions of total amount of MDCT examinations performed for year with an estimate annual increase rate of 8 % [4, 5]. The main concern in the use of procedures with radiation is the potential long-term effect of radiation exposure, namely the association between radiation and increased cancer risk [6, 7]. International guidelines considered every radiation dose exposure, a possible risk of patients [8]. Even though a “cumulative risk” is under strong debate and criticised by many international radiation protection authorities, some reports emphasise that some
patients receive very high cumulative dose from multiple radiological examinations [9]. Associated health risks from medical imaging are of major concern especially in young patients submitted to many radiological procedures in a short period of time due to trauma [3]. It is well known that factors as patient age, gender and fraction of radiation are of impact on potential injury from medical radiation [10]. The aim of the present research was to evaluate the number of repeat MDCT examinations in young adult patients in the last 4 years in a single trauma centre (University Hospital of Palermo Policlinico) which potentially serve more than 1 million habitants.

Materials and methods

We have identified retrospectively patients submitted to more than a MDCT study for major trauma in a referral regional trauma centre. Our centre is supplied with three MDCT facilities in the A&E department and other two in the main radiology building (the study was approved by the local ethical committee). The MDCT unit dedicated in the A&E Department and another emergency dedicated unit in the main radiology building are opened 24 h per day, 7 days a week (7 days a week, 24 h a day). From the radiology information system (RIS Elefante Agfa®), we have selected younger adults (range 14–40 years) who performed more than one MDCT between June 2010 and June 2014. Referral reasons for each examination were derived from the structured reports on RIS to select only trauma patients. Case of repeated MDCT examinations in subsequent weeks, for reasons different from trauma and sequel, was excluded from the sample. Dose data were derived from Picture Archiving and Communication System (PACS Impax Agfa®). For each patient, a spreadsheet file excel was build from RIS and PACS metadata including: clinical purpose, date, age, MDCT equipment, type of examination, use contrast compound, number of phases performed, body part examined and dose report. All the examinations were performed with two different MDCT apparatuses: a 128-slice MDCT (SOMATON® Definition AS Siemens Healthcare installed in December 2011) and a 16-slice MDCT (Bright Speed Elite® GE medical system installed in March 2010), which is the mainly emergency dedicated apparatus. For each examination, the MDCT scanners provided the computed tomography dose index (CTDI vol) and dose length product (DLP) values in Gy*cm. In the examined period, the iterative software algorithm to reduce dose was not available in our department and was installed in July 2014. Every 6 months, both MDCT apparatuses are controlled and CTDI has been measured and is measured by using phantom measure according to the European guidelines EUR16262/1998 [11]. The measured value has been verified to be within ±10 % of the console displayed data [11]. In order to evaluate the estimated effective total dose and the effective dose to the various organs (such as breasts, testicles, ovaries, prostate and eye lenses), we have used the CT-EXPO® software version 2.2 (Hannover Germany) that provide information about estimated effective dose for various MDCT apparatuses. Once the user sets the acquisition parameters such as tension (kV), current (mA) and duration of the examination, part of body exposed and patient’s gender, the software provided estimate values of the effective total dose and the estimate organ dose. However, the software cannot take into account the differences among patients in terms of mass, height and width; this involves that for a given examination type the DLP values could differ slightly among patients. In order to overcome this issue, for each examination of each patient, the dose values were rescaled with respect to the DLP values provided by the MDCT scanners. MDCT main segments investigated were as follows: full-body examination as head, chest, abdomen and pelvis 14; chest, abdomen and pelvis 13; head and spine 11; head and chest 10; and other 11. For each dose value, we have obtained the corresponding histogram plots and their average and median values.

Results

In our department in the selected 4-year period, we have identified 32,352 on 107,476 (30.01 %) patients referred for trauma submitted to MDCT. We found, through our retrospective analysis, 249 traumatic patients (71 females and 178 males) who underwent more than one MDCT (average 2.8 examinations) in a short period of time (median 4 days) for diagnosis, follow-up and eventual surgical complications due to trauma. The mean patient age was 29 years (age range 14–40 years; Table 1). The age distribution showed two age peaks around 24 years and between 35 and 37 years. In fact, deviations from uniform distribution

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Maximum, minimum, mean and median values of age, CTDIw, CTDIvol, DLPw and effective dose for the patients investigated</th>
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<tr>
<td>Age</td>
<td>CTDIw</td>
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<tr>
<td>Maximum value</td>
<td>40.41</td>
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<tr>
<td>Minimum value</td>
<td>14.02</td>
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<tr>
<td>Mean value</td>
<td>28.57</td>
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<tr>
<td>Median value</td>
<td>39.27</td>
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<td>Standard deviation</td>
<td>7.03</td>
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can be noted for young patients (below 20 years) and for patients with age around 40 years (Fig. 1). Distribution of MDCT scans divided for anatomical district showed a vast majority of head examinations (532; 64.2 %) followed by abdomen (126; 15.2 %) and chest (79; 9.5 %). Other segments were cervical spine 32, maxillo-facial 17, lumbar spine 16, dorsal spine 10, other segments 11, extremities 3 and neck 2 (Fig. 2). A number of 103/259 (41.3 %) patients have performed more anatomical districts (Table 2). Many examinations were conducted with more than one phase for the use of contrast compound; however, in 37 cases of noncontrast head CT, a second acquisition was performed due to artefact in uncooperative patients; this event has been considered as a factor that increased dose exposure in these populations. Second and eventual subsequent MDCT scan after first examination was mainly focused on a single
anatomical district, and the vast majority was focussed on the head (66; 64%). We have observed a large variability in CTDIvol and DLPw; consequently, effective dose can vary significantly for different district examined and acquisition modality (multiphase examinations) used in trauma assessment, follow-up and eventual surgical follow-up or complications due to trauma (Table 1). For the analysis of the effective dose absorbed by patients in the sample, we have estimated that the value of mean effective dose was about 27 mSv (range from 3 to 297 mSv). The distribution analysis was characterised by high values in the lower dose range (below 20 mSv); however, in 29 patients, the effective dose was found to be higher than 20 mSv (Fig. 3). The dose analysis performed provided also dose distributions to same organs of interest such as breasts, testicles, heart and eye lenses and pointed out the presence of an intense peak at low doses, but there is a tail of higher doses. Looking at the equivalent dose to breasts (Fig. 4), the estimated mean value was about 11 mSv (range from 0.09 to 142 mSv). The distribution was characterised by high values in the low dose range (about 80% of doses in the breasts were smaller than 10 mSv). Equivalent dose for the testicles (Fig. 5); the estimated mean value was about 11 mSv (range from 0 to 202 mSv). Similar values were found for the ovaries (Fig. 6). Regarding equivalent dose for the heart (Fig. 7), the estimated mean value was about 14 mSv (range from 0 to 248 mSv). In this case, more than 70% of examinations were characterised by doses for the heart smaller than 10 mSv. Regarding equivalent dose to eye lenses (Fig. 8), the estimated mean value was quite high (257 mSv) (range from 0 to 1943 mSv). We also have observed a correlation between days of the week, mostly on weekends, and repetition of MDCT examination. The interval of repeated examination is mainly in 24–72 h from the first access to the A&E department. Patient gender did not play any role on the number of repeated examinations. Some traumatic patients received an impressive cumulative radiation dose as a 25-year man (suicide attempt) rising an amount of 25 MDCT examinations in 6 months (the patient died in intensive care unit). The total effective dose absorbed by this patient was about 200 mSv.
Discussion

MDCT is the main choice in case of evaluation of traumatic patients, and their subsequent monitoring determines otherwise a significant increase in radiation exposure in general population [12]. In the USA, dose of radiation from medical imaging has increased by a factor of nearly six from 1980s [13, 14]. Young adults have been the focused population’s group for long life expectancy, and they are generally considered more sensitive to damage of ionising radiations (RI). MDCT is the modality that makes the greatest contribution, compared to other radiological procedures, to dispense RI at the population. Our results

Fig. 4 Distribution of breast doses absorbed in female patients

![Breast Dose Distribution](image)

Fig. 5 Distribution of testicle doses absorbed for male patients

![Testicle Dose Distribution](image)
showed that the number of traumatic young adult patients submitted to MDCT is quite very high and mainly due to traffic accident. The data could be explained looking to the statistics of traffic accident; in fact, in Italy, in 2013, there were 3385 deaths and 257,421 people seriously injured in car accident; among them, one-third (968) had an age comprised between 20 and 44 years with a (to) peak for young adults of 20–24 years and adults of 40–44 years [15]. These data lead to an increase in number of diagnostic tests, in most cases of MDCT whose diagnostic benefit is beyond any doubt, but it creates the problem of multiple doses in patients with a long life expectancy. This situation has generated hot debate regarding the relationship between cumulative doses and increased risk of cancer. Despite the fact
that cumulative effective dose (CED) has been criticised by different authorities as Radiation Dose Summit by NIBIB (National Institute of Biomedical Imaging and Bioengineering) that “is known quantitatively about the benefits of specific imaging studies in a wide range of clinical settings and the risks of low level radiation exposure to individuals, it will be very difficult this benefit-risk trade-offs accurately” [9]. Cumulative radiation dose is not widely accepted, but we have to emphasise that repeated examinations in a short time in young patients are certainly of some concerns [14]. Also looking to organ doses observed for both classical cancer effect (breast, ovaries and testicles) and noncancer effect (eye lens hearth) compared to recent IRCP guidelines, we found that some trauma patients have received impressive dose that in some case exceeds limits for professional exposure. For cancer effect, probably two major studies emphasised risks of long-term cancer effects as Pearce [16] in British childhood populations and Mathews [17] data in Australian children and adolescent populations. Both deduce that interference of CT scans causes excess cancer risk in exposed populations. Eye lens dose is of concerns for the increased prevalence of eye lens opacities in staff exposed to radiation levels below the thresholds as established by the International Commission on Radiological Protection (ICRP) 60 in 1990 and ICRP Publication 103 of 2007 [8]. The ICRP commission has now reviewed, after recent epidemiological evidence, the set threshold in absorbed dose for the lens of the eye is 0.5 Gy for the entire life span (ICRP Statement on Tissue Reactions 2011). For occupational exposure in planned exposure situations, the recommendation of the commission is an equivalent dose limit for the lens of the eye of 20 mSv in a year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv [18]. This recommendation is present in the new Council Directive 2013/59/ Euratom laying down basic safety standards for protection against exposure to ionising radiations [19]. Other noncancer effect regards the circulatory system. In particular, it is well known that high doses (>5 Gy) of ionising radiation exposure produce damage to the heart and coronary arteries. In recent years, many studies have investigated cardiovascular diseases [20–26], proposing that doses higher than 0.5 Sv cause an excess relative risk [22, 23]. This excess relative risk is calculated on 5% per mSv [23]. Even though for doses smaller than 0.5 Sv the assessment of damage is difficult and various studies are in progress, a possible increase in risk of cardiovascular diseases should be taken into account for repeated MDTC examinations. Previous experience in trauma patients was reported by You et al. [3] in trauma patients (11,676) submitted to different radiological examinations with either conventional radiograph and MDCT; cumulative effective dose (CED) in the 231 cases of repeated or multiple radiological examinations was 20 mSv, but 27 patients received a CED of 100 mSv. In paediatric trauma population, Tepper et al. [27] evaluated the CED in a single institution and identified retrospectively 49 boys and 27 girls who in the first 24 h performed a mean of 3.4 MDCT scans during initial evaluation with an average effective dose of 8.79 mSv. Tepper et al. concluded that epidemiological studies are needed to definitively show the

Fig. 8 Distribution of eye lens doses absorbed by patients
increased risk of cancer from repeated MDCT scans. You et al. [3] observed young traumatic patients in emergency department performing multiple diagnostic procedures, mainly MDCT; he described a mean CED per medical visit of 2.6 mSv, with two age peaks between 15–19 years and 40–44 years. In the patients in the 0- to 14-year age group, the most common injury mechanism was slip-down injury. You et al. [3] data are similar to ones in our population. The patients included in the study were referred for major trauma, in most cases traffic accident. All the examinations were firstly justified according hospital guidelines; the diagnostic information obtained from MDCT were relevant for the survival of the patient, through the identification of lesions quickly and efficiently, but the relatively high-radiation doses associated with MDCT compared with conventional radiography may raise possible long-term health risk [16]. Although there is no evidence and unique guideline on risks resulting from repeated exposure to IR, the growing number of repeated examinations, especially MDCT examinations in young adults, is of some concern. Young adults have, in radiobiological terms, a long life expectancy, and the lack of certain knowledge about the consequences of repeated exposure to low doses cannot be taken in account [16]. Risks associated with excessive exposure to radiation needs to consider alternative-imaging modality (as ultrasound and MR) in order to reduce radiation risk in this population. MDCT in trauma seems to be a “victim” of his own success and in many cases is the gold standard to assess trauma lesions for speed, availability and diagnostic performance; however, use of MDCT should be reduced in control examination if possible. When MDCT scan is performed it is important to follow strictly the ALARA (As Low As Reasonably Achievable) principle and adapt scan parameters to lower dose setting parameters. Other dose reduction strategy obviously includes examination of the anatomical body region of interest and avoids scan repetition unless it is strongly clinically useful [9]. Iterative software reduces single and cumulative patient radiation dose and would be very useful in trauma centre [28]. Probably, software that monitors and tracks radiation dose may help radiologist and referring physicians to balance repeated examination and, depending on MR availability, avoid modalities that imply significant radiation dose as MDCT. CED in trauma patients results in a small sample to a significant radiation exposure similar or higher to professional exposure and in case of young patients is of some concerns. However, only long-term prospective multicentre studies will be able to estimate the effective cumulative radiation risk.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval The study is retrospective, so for this type of study, formal consent is not required. This article does not contain any studies with animals performed by any of the authors.

References