Computed tomography with low-dose radiation versus standard-dose radiation for diagnosing fractures: systematic review and meta-analysis

Márcio Luís Duarte[I], Lucas Ribeiro dos Santos[II], Acary Souza Bulle Oliveira [III], Wagner Iared[IV], Maria Stella Peccin[V]

Evidence-Based Health Department and Neurology Department, Universidade Federal de São Paulo (UNIFESP), São Paulo (SP), Brazil

[I]MD, MSc. Musculoskeletal Radiologist, WEBIMAGEM, São Paulo (SP), Brazil; and Doctoral Student in Evidence-based Health Program, Universidade Federal de São Paulo (UNIFESP), São Paulo (SP), Brazil.
https://orcid.org/0000-0002-7874-9332

[II]MD, MSc. Endocrinologist and Professor of Physiology and Medical Clinic, Centro Universitário Lusíada (UNILUS), Santos (SP), Brazil; and Doctoral Student in Evidence-based Health Program, Universidade Federal de São Paulo (UNIFESP), São Paulo (SP), Brazil.
https://orcid.org/0000-0001-7897-1198

[III]MD, PhD. Affiliated Professor, Department of Neurology, Universidade Federal de São Paulo (UNIFESP), São Paulo (SP), Brazil.
https://orcid.org/0000-0002-6986-4937

[IV]MD, PhD. Supervising Professor, Evidence-Based Health Postgraduate Program, Universidade Federal de São Paulo (UNIFESP), São Paulo (SP), Brazil.
https://orcid.org/0000-0002-6426-5636

[V]PT, PhD. Associate Professor, Department of Human Movement Sciences, and Advisor, Evidence-Based Health Postgraduate Program, Universidade Federal de São Paulo (UNIFESP), São Paulo (SP), Brazil.
https://orcid.org/0000-0003-0329-4588

ABSTRACT

BACKGROUND: Computed tomography (CT) accounts for 13% of all radiological examinations in the United States and 40-70% of the radiation that patients receive. Even with the advent of magnetic resonance imaging (MRI), CT continues to be the gold standard for diagnosing bone fractures. There is uncertainty as to whether CT with a low radiation dose has a fracture detection rate similar to that of standard-dose CT.

OBJECTIVE: To determine the detection rate of low-dose radiation CT and standard-dose radiation CT for fractures, in patients with suspected fractures.

DESIGN AND SETTING: Systematic review of comparative studies on diagnostic accuracy within the evidence-based health program at a federal university in São Paulo (SP), Brazil.

METHODS: We searched the electronic databases Cochrane Library, MEDLINE, EMBASE and LILACS up to June 29, 2020, for studies evaluating the detection rates of low-dose CT and standard-dose CT for diagnosing bone fractures. The Research Triangle Institute (RTI) item bank tool was used for methodological quality evaluation.

RESULTS: The fracture detection rate according to the number of bones evaluated, using CT with low-dose radiation was 20.3%, while with standard-dose radiation it was 19.2%, and the difference between the methods was not significant. The fracture detection rate according to the number of patients, using CT with low-dose radiation was 56.0%, while with standard-dose radiation it was 58.7%, and this difference between the methods was not significant, either.

CONCLUSION: CT with low-dose radiation presented detection rates similar to those of CT with standard-dose radiation, regardless of the bones evaluated.

REGISTRATION NUMBER: CRD42019148491 at the PROSPERO database.

INTRODUCTION

Ionizing radiation such as X-rays is a singular form of energy that surmounts the binding energy of electrons that orbit atoms and molecules.[1] In biological material exposed to X-rays, the most common consequential scenario is that this creates hydroxyl radicals from interactions between X-rays and water molecules. These radicals, in turn, interact with deoxyribonucleic acid (DNA) to cause breakage of bonds or damage to the base.[1] Thus, mutations, chromosomal translocations and fusions between genes can occur, which in some cases may lead to cancer.[1]

All X-ray-based imaging methods have the characteristic in common of a trade-off between image quality and radiation dose, since all forms of ionizing radiation can damage tissues.[2] In patients undergoing radiographic and/or tomographic monitoring, the patient's exposure to radiation needs to be considered, and this poses a challenge to radiologists regarding dose reduction.[3,4]

The main concern in diagnostic imaging is that a stochastic lesion of radiation-induced cancer could develop, which can occur with any radiation dose.[5-7] Conversely, deterministic effects occur only when the threshold has been exceeded and, above that, the incidence and severity of the injury increase with the radiation dose.[6,7] It also needs to be taken into account that the pediatric population is 10 times more sensitive to radiation than adults.[8]

To date, no safe dose of ionizing radiation, below which there is no risk of cell damage and subsequent risk of cancer, has been established.[9,10] However, it has been estimated in the United States that about 1.5%-2.0% of all malignancies can be attributed to radiation from computed tomography (CT) scans.[1,6] Taking all imaging examinations into account, this proportion ranges

from 0.6% to 3.6%.[11] The risk of cancer increases by 0.01% for each mSv emitted in imaging tests.[12]

Thus, there is a growing awareness of the need to use the lowest possible radiation dose level that is capable of providing appropriate diagnostic information, also known as the ALARA principle (As Low As Reasonably Achievable).[9,11-24]

CT is the gold standard for diagnosing fractures,[10,25-27] characterizing them in greater detail, identifying hidden fractures and showing incomplete union.[27,28] In musculoskeletal radiology, low-dose CT has shown good results in studies with pre and postoperative scoliosis evaluations, as well as in diagnosing lytic injuries and fractures in patients with multiple myeloma.[5,29,30] However, when metallic components are present in the bones studied, standard-dose CT scans have better image quality, with fewer artifacts, than low-dose CT scans.[31]

OBJECTIVES

The aim of this study was to determine the detection rates of computed tomography with low radiation dose and computed tomography with standard radiation dose for fractures, independent of the bone suspected, in patients with suspected fractures.

METHODS

Study model

The study model followed the guidelines for systematic reviews of diagnostic accuracy studies, in the Cochrane Diagnostic Reviewer's Handbook version 5.1.

Inclusion criteria

The search of the literature was performed in accordance with the guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Studies evaluating the diagnostic accuracy and detection rates of fractures in patients with suspicion of fractures, evaluated using low-dose CT and standard-dose CT were included regardless of publication status and regardless of severity and time of disease. We did not put any restrictions on patient age, origin, language or publication status of the study. There was no exclusion regarding population size or patient age. In cases of missing information, the authors were contacted by email.

Participants

The participants in this study were men and women of all ages with suspected bone fractures who underwent low-dose CT or standard-dose CT.

Selection of studies and data extraction

The studies selected were those that were potentially eligible for inclusion in terms of relevant articles or abstracts from reference journals. Two authors performed independent selections for eligibility. In cases of disagreement, a third author was consulted. Data extraction was performed using a standardized form.

Evaluation of methodological quality

Eligible studies with a control group were evaluated using the QUADAS 2 tool (Quality Assessment of Diagnostic Accuracy Studies).[32] In all eligible studies, the RTI Item Bank questionnaire was used. This is a tool that focuses on evaluation of biases and precision).[33,34]

All forest plots were made using the Review Manager software (RevMan), version 5.3, in order to obtain sensitivity and specificity values and the respective 95% confidence intervals (CI). We expressed dichotomous data as odds ratios (OR) with a 95% CI and continuous data as mean differences (MDs) with 95% CI. The study was approved by our institutional review board, under the approval number 7184070819, dated October 2, 2019. The review was approved by the PROSPERO database. No funding or support was provided for this study.

Research methods for choosing studies

A thorough systematic search of the literature was performed in June 2020, in the PubMed, EMBASE, Cochrane Library and LILACS online scientific publication databases, for all original-language publications. The search was conducted using the medical subject headings (MeSH). The MeSH terms used included the following: fractures, bone; radiation dosage; tomography, X-ray computed. The reference lists of the studies included and the main reviews on the subject were also evaluated. Manual searches were also carried out in the lists of references. The full search strategy is presented in **Table 1**.

RESULTS

Studies selected

The search for this systematic review yielded 468 studies using the following MeSH terms: fractures, bone; radiation dosage; tomography, X-ray computed.

There were no studies in which low-dose CT and standard-dose CT were performed on the same patient. Also, no study had a control group. Therefore, it was not possible to assess accuracy, and only the detection rate could be evaluated in the meta-analysis. A total of five studies fulfilled the inclusion criteria and were included in qualitative analysis (**Figure 1**).[16,17,18,35,36] Two studies did not provide all the data.[16,35] Konda et al. was not used because it did not have the necessary blinding for inclusion in this systematic review.[28]

Analysis on the studies

Lee et al. conducted two studies: one published in 2017[17] and another in 2018.[18] In both, the period between January

and September 2016 was assessed. However, these studies were performed using different devices, with 64 channels and 320 channels, respectively. In Lee et al.,[18] there were evaluations by two doctors: one from the emergency department and one radiologist. For the statistical evaluation, we use the data from the radiologist because this specialist has the responsibility for issuing reports.

Four studies reported the numbers of patients evaluated and how many had fractures.[17,18,35,36] Four studies reported the numbers of bones evaluated and how many had fractures.[16–18,36] There was no study with a control group.

All the studies reported that the reduction in the radiation dosage of the CT scans was around 50%. The CT devices, bones evaluated and radiation dosages in the studies reviewed are shown in **Table 2**.[16-18, 35,36]

Table 1. Search strategies used in each of the databases

Database	Search strategy
Cochrane Library	#1: MeSH descriptor: [Fractures, Bone] explode all trees. #2: MeSH descriptor: [Radiation Dosage] explode all trees. #3: MeSH descriptor: [Tomography, X-Ray Computed] explode all trees. #4: #1 AND #2 AND #3
MEDLINE	#1: "Fractures, Bone"[MeSH] OR (Broken Bones) OR (Bone, Broken) OR (Bones, Broken) OR (Broken Bone) OR (Bone Fractures) OR (Bone Fracture) OR (Fracture, Bone) OR (Spiral Fractures) OR (Fracture, Spiral) OR (Fractures, Spiral) OR (Spiral Fracture) OR (Torsion Fractures) OR (Fracture, Torsion) OR (Fractures, Torsion) OR (Torsion Fracture) #2: "Radiation Dosage"[MeSH] OR (Dosages, Radiation) OR (Radiation Dosages) OR (Dosage, Radiation) OR (Sievert Units) OR (Units, Sievert) OR (Sv Radiation Dose Equivalent) OR (Gray Units) OR (Units, Gray) OR (Gy Radiation) #3: "Tomography, X-Ray Computed"[MeSH] OR (X-Ray Computed Tomography) OR (Tomography, X-Ray Computerized) OR (Tomography, X Ray Computerized) OR (Computed X Ray Tomography) OR (X-Ray Computer Assisted Tomography) OR (X Ray Computer Assisted Tomography) OR (Tomography, X-Ray Computer Assisted) OR (Tomography, X Ray Computer Assisted) OR (Computerized Tomography, X Ray) OR (Computerized Tomography, X-Ray) OR (X-Ray Computerized Tomography) OR (CT X Ray) OR (CT X Rays) OR (X Ray, CT) OR (X Rays, CT) OR (Tomodensitometry) OR (Tomography, X Ray Computed) OR (X Ray Tomography, Computed) OR (X-Ray Tomography, Computed) OR (Computed X-Ray Tomography) OR (Tomographies, Computed X-Ray) OR (Tomography, Computed X-Ray) OR (Tomography, Xray Computed) OR (Computed Tomography, Xray) OR (Xray Computed Tomography) OR (CAT Scan, X Ray) OR (CAT Scan, X-Ray) OR (CAT Scans, X-Ray) OR (Scan, X-Ray CAT) OR (Scans, X-Ray CAT) OR (X-Ray CAT Scan) OR (X-Ray CAT Scans) OR (Tomography, Transmission Computed) OR (Computed Tomography, Transmission) OR (Transmission Computed Tomography) OR (CT Scan, X-Ray) OR (CT Scan, X Ray) OR (CT Scans, X-Ray) OR (Scan, X-Ray CT) OR (Scans, X-Ray CT) OR (X-Ray CT Scan) OR (X-Ray CT Scans) OR (Computed Tomography, X-Ray) OR (Computed Tomography, X Ray) OR (X Ray Computerized Tomography) OR (Cine-CT) OR (Cine CT) OR (Electron Beam Computed Tomography) OR (Electron Beam Tomography) OR (Beam Tomography, Electron) OR (Tomography, Electron Beam) OR (Tomography, X-Ray Computerized Axial) OR (Tomography, X Ray Computerized Axial) OR (X-Ray Computerized Axial Tomography) OR (X Ray Computerized Axial Tomography) #4: #1 AND #2 AND #3
EMBASE	#1: ('fracture'/exp OR 'bone cement fracture' OR 'bone fracture' OR 'closed fracture' OR 'fracture' OR 'fractures' OR 'fractures, bone' OR 'fractures, closed' OR 'skeleton fracture' OR 'unstable fracture') #2: ('radiation dose'/exp OR 'dose rate, radiation' OR 'dose, radiation' OR 'radiation dosage' OR 'radiation dose' OR 'radiation dose absorption' OR 'radiation dose output') #3: ('x-ray computed tomography'/exp OR 'ct scan' OR 'ct scanning' OR 'tomography, x-ray computed' OR 'x-ray computed tomography') #4: #1 AND #2 AND #3
LILACS	#1: mh: "Fraturas Ósseas" OR (Fractures, Bone) OR (Fracturas Óseas) OR (Fratura) OR (Fraturas) OR (Fraturas de Ossos) OR (mh:C26.404) #2: "Dose de Radiação" OR (Radiation Dosage) OR (Dosis de Radiación) OR (Dosage, Radiation) OR (Gray Units) OR (Gy Radiation) OR (Sv Radiation Dose Equivalent) OR (Dosages, Radiation) OR (Radiation Dosages) OR (Units, Gray) OR (Units, Sievert) OR (Sievert Units) OR (mh: E05.799.513) OR (mh: G01.750.740) OR (mh: N06.850.810.250) OR (mh: SP8.473.654.412.062.116.157) #3: mh:"Tomografia Computadorizada por Raios X" OR (Tomography, X-Ray Computed) OR (Tomografía Computarizada por Rayos X) OR (TAC por Raios X) OR (Tomografia por Raios X Computadorizada) OR (Tomografia Axial Computadorizada por Raios X) OR (TC por Raios X) OR (Tomografia Computadorizada por Transmissão) OR (Tomografia Computadorizada por Transmissão de Raios X) OR (Tomografia Computadorizada Dinâmica) OR (Cine-TC) OR (Tomodensitometria) OR (Tomografia Computadorizada de Feixe de Elétrons) OR (Tomografia de Feixe de Elétrons) OR (Tomografia Computadorizada) OR (mh: E01.370.350.350.810) OR (mh: E01.370.350.600.350.700.810) OR (mh: E01.370.350.700.700.810) OR (mh: E01.370.350.700.810.810) OR (mh: E01.370.350.825.810.810) #4: #1 AND #2 AND #3

Detection rate in relation to number of bones

Bone evaluations were provided and cited with regard to each method, in four studies: Jin et al.,[16] Lee et al.,[17] Lee et al.[18] and Yi et al.[36] A total of 7719 bones were evaluated. Out of the 3876 bones evaluated by means of standard-dose CT, 744 had fractures: a detection rate of 19.2%. Out of the 3,843 bones evaluated by means of low-dose CT, 782 showed fractures: a detection rate of 20.3%. All of this information is shown in **Figure 2**.

Detection rate in relation to number of patients

Patient assessments were provided and cited with regard to each method, in four studies: Lee et al.,[17] Lee et al.,[18] Mulkens et al.[35] and Yi et al.[36] A total of 996 patients were evaluated. Out of the 453 patients assessed by means of standard-dose CT, 266 had fractures: a detection rate of 58.7%. Out of the 543 patients evaluated by means of low-dose CT, 304 had fractures: a detection rate of 56.0%. All of this information is shown in **Figure 3**.
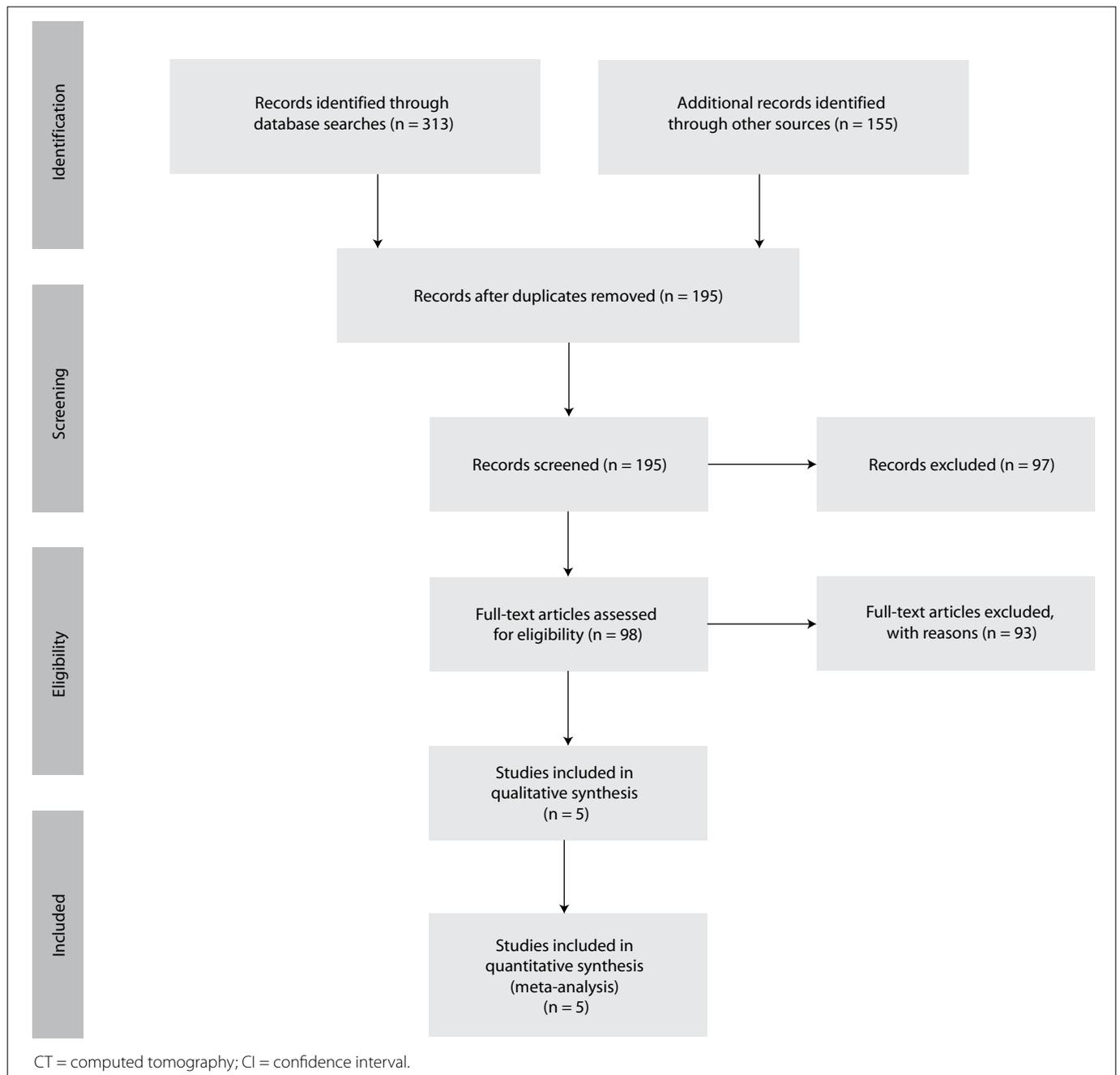

CT = computed tomography; CI = confidence interval.

Figure 1. Summary of the study selection process.

DISCUSSION

The detection rate of low-dose CT in relation to evaluation of the number of fractured bones was 20.3%, while standard-dose CT yielded a rate of 19.2%. The difference between the methods was not significant. The detection rate of low-dose CT in relation to evaluation of the number of patients with fractures was 56.0%, while standard-dose CT yielded a rate of 58.7%. Here too, the difference between the methods was not significant.
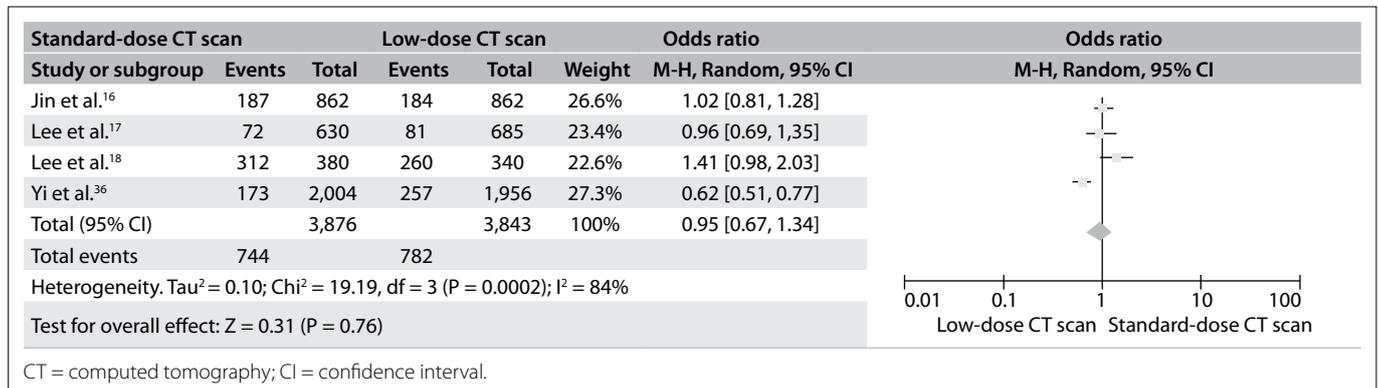
A separate assessment on joints, done in only a single study, showed a similar conclusion. Yi et al.[36] demonstrated that fractures of the bones of the shoulder, pelvis, ankle and wrist had a similar detection rate through both low-dose CT and standard-dose CT, in terms of the evaluations on both the number of patients and the number of bones.

Lee et al.[18] demonstrated good reproducibility among the evaluators, including between those from different specialties (a doctor in the emergency department and a radiologist). All the evaluators

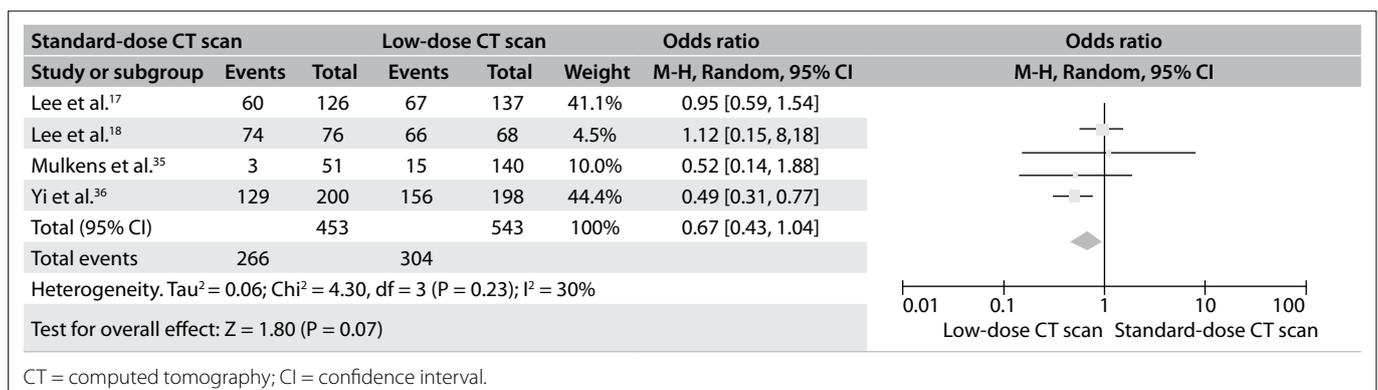**Table 2.** Radiation doses used in computed tomography in each of the studies reviewed

Study	CT device	Bone evaluated	Low-dose CT radiation	Standard-dose CT radiation
Jin et al.[16]	64 MDCT	Rib	1.24 mSv	5.75 mSv
Lee et al.[17]	64 MDCT	Lumbar vertebra	2.1 mSv	4.9 mSv
Lee et al.[18]	320 MDCT	Lumbar vertebra	2.1 mSv	5.4 mSv
Mulkens et al.[35]	6 MDCT	Cervical vertebra	1.57 mSv	3.75 mSv
	16 MDCT	Cervical vertebra	1.37 mSv	3.57 mSv
Yi et al.[36]	64 MDCT	Ankle	0.8 mSv	1.4 mSv
		Pelvis	3.9 mSv	7.4 mSv
		Shoulder	2.9 mSv	5.8 mSv
		Wrist	0.7 mSv	1.2 mSv

CT = computed tomography; MDCT = multi-detector computed tomography.

Standard-dose CT scan			Low-dose CT scan		Weight	Odds ratio M-H, Random, 95% CI	Odds ratio M-H, Random, 95% CI
Study or subgroup	Events	Total	Events	Total			
Jin et al.[16]	187	862	184	862	26.6%	1.02 [0.81, 1.28]	
Lee et al.[17]	72	630	81	685	23.4%	0.96 [0.69, 1.35]	
Lee et al.[18]	312	380	260	340	22.6%	1.41 [0.98, 2.03]	
Yi et al.[36]	173	2,004	257	1,956	27.3%	0.62 [0.51, 0.77]	
Total (95% CI)		3,876		3,843	100%	0.95 [0.67, 1.34]	
Total events	744		782				
Heterogeneity. Tau^2 = 0.10; Chi^2 = 19.19, df = 3 (P = 0.0002); I^2 = 84%							
Test for overall effect: Z = 0.31 (P = 0.76)							

CT = computed tomography; CI = confidence interval.

Figure 2. Forest plot: comparison demonstrating that there was no significant difference between low-dose CT and standard-dose CT regarding the detection rate for bone fractures.

Standard-dose CT scan			Low-dose CT scan		Weight	Odds ratio M-H, Random, 95% CI	Odds ratio M-H, Random, 95% CI
Study or subgroup	Events	Total	Events	Total			
Lee et al.[17]	60	126	67	137	41.1%	0.95 [0.59, 1.54]	
Lee et al.[18]	74	76	66	68	4.5%	1.12 [0.15, 8,18]	
Mulkens et al.[35]	3	51	15	140	10.0%	0.52 [0.14, 1.88]	
Yi et al.[36]	129	200	156	198	44.4%	0.49 [0.31, 0.77]	
Total (95% CI)		453		543	100%	0.67 [0.43, 1.04]	
Total events	266		304				
Heterogeneity. Tau^2 = 0.06; Chi^2 = 4.30, df = 3 (P = 0.23); I^2 = 30%							
Test for overall effect: Z = 1.80 (P = 0.07)							

CT = computed tomography; CI = confidence interval.

Figure 3. Forest plot: comparison demonstrating that there was no significant difference between low-dose CT and standard-dose CT regarding the detection rate for patients with fractures.

analyzed all the CT scans, in terms of both the number of patients and the number of bones. The detection rate for the emergency room physician was 80% in the bone assessments using standard-dose CT whereas with low-dose CT it was 73%. The detection rate for the radiologist was 82% in the bone assessments using standard-dose CT and 76% using low-dose CT. The detection rates in the evaluation according to patients was exactly the same for the two professionals: 97% with both standard-dose CT and low-dose CT.

Mulkens et al.[35] assessed the quality of the images in low-dose CT compared with the quality in standard-dose CT. In analysis on the images done by different evaluators, it was found that although low-dose CT had lower image quality than standard-dose CT, the examination with low-dose CT preserved sufficient quality for accurate assessment of fractures. This study also demonstrated good reproducibility among the evaluators with regard to diagnosing fractures, as shown by Lee et al.[18]

Trauma is responsible for 19% of all fractures, and the incidence of these fractures also increases with age. Brazil, for example, leads the world statistics on traffic accidents, which are the predominant cause of trauma in this country.[37,38] Thus, high numbers of fractures occur in Brazil, which requires large numbers of CT scans. Reduction of the radiation dose from CT scans in Brazil is valuable and important because this will diminish costs.

CT accounts for 13% of all radiological examinations in the United States and between 40% and 70% of the radiation that patients receive.[39-41] It also needs to be taken into account that CT is responsible for the greatest exposure to radiation among trauma patients, since they frequently undergo CT scans.[7,9,15,22,42,43] Although bones are only minimally affected by radiation, the bone marrow is the most radiosensitive organ in the body.[36] Although CT is responsible for 40-70% of patients' radiation doses,[39-41] this percentage goes up to 97.5% in the case of hospitalized patients.[12] In the pediatric population, the effective dose can be up to three times higher than in the adult population.[24] The risk of developing cancer later in life is more powerfully predicted when effective doses of 5.6 mSv for the lumbar spine and 10.0 mSv for the whole dorsal spine are administered through CT, measured by means of radiography.[1,10,44]

Given that, so far, no feasible safe dose of ionizing radiation that does not present a risk of cell damage and consequently cancer has been determined,[9] there is great interest in reducing radiation levels while maintaining the rate of fracture detection. This is even more so in the pediatric population, given that reducing the doses administered to children reduces the incidence of cancer decades after exposure. In 2007, four million CT scans were performed among children in the United States.[1]

CT can be performed with much lower doses of radiation than the standard radiation dose, despite the consequent increase in image noise and reduced image quality.[5,45–47] It can even be done using the same radiation dose as in radiography.[30,48] It seems to be particularly advantageous to indicate a reduced radiation protocol for CT on the extremities, because the area scanned is smaller than that of other regions of the human body, like the abdomen, for example.[49]

Moreover, it needs to be borne in mind that multislice CT tubes have a production life of around 800,000 slice and their average cost is 30,000 pounds (approximately 41,667.00 US dollars or 227,334.00 reais).[50] If the radiation dose were to be halved, the useful life of the CT tube would be increased fourfold, thereby giving rise to important savings.[50] In this regard, it also needs to be remembered that the number of CT scans performed is constantly increasing, year by year. In the United States, 70 million CT scans were performed in 2014, which was 20 times more than had been documented in 1980.[5]

The following methods can be used to reduce the patient's radiation dose received through computed tomography:

- Reducing the milliampere-second setting: if the milliampere-second value is reduced by 50%, the radiation dose will be reduced by the same amount.[51]
- Increasing the pitch: the radiation dose is inversely proportional to the pitch when all other factors are kept constant.[51]
- Changing the milliamp setting according to the patient's size: the milliamp-second value can be reduced proportionally with smaller sizes of patients.[51]
- Reducing the x-ray beam energy (kilovolt peak): reducing the beam energy results in a reduced radiation dose when all other factors are kept constant.[51]
- Model-based iterative reconstruction: this provides lower image noise and fewer artifacts; it has been designed to complement other dose-reduction methods while preserving diagnostic image quality.[52]
- Deep learning: this can distinguish noise from signal in CT images and, consequently, can boost signal while diminishing noise.[53]
- Machine-learning algorithms, as a subfield of artificial intelligence: different types of machine learning (linear regression, regression trees, bagged regression trees, Gaussian process regression, support vector machine (SVM) regression or neural networks) can reduce the radiation dosage, to adapt to new circumstances and identify and rate standards.[4]

Within the scope of public health interest, the importance of reduction of this radiation dose is in relation to the following:
- Reduction of long-term incidence of malignancies.
- Reduced spending on high-cost medications and procedures for malignant neoplasms, i.e. chemotherapy, radiotherapy, surgery, hospitalization, etc.
- Increasing the population's quality of life.
- Reduced expenditure on CT tubes.

These changes would give rise to significant savings. They would enable reallocation of funds to areas that need more attention. Thus, this is a matter of enormous administrative relevance since, in addition to the savings already mentioned, new investments would cease to be necessary (exchange of devices, purchase of software and relocation of devices), given that only adjustments to the regulation of CT examination protocols are needed.[51]

In addition, in cases of patients with diseases that require CT monitoring, low-dose CT scans provide the possibility of shorter time intervals between examinations, thus making it possible to adjust the treatment when necessary and, hence, making it possible to avoid worsening of the disease.[54]

The present findings have some implications for future research. Low-dose CT was shown here to maintain the bone fracture detection rate and was previously shown to be effective for evaluation of pulmonary nodules[55,56] and lithiasis in the urinary tract.[57] In the latter, moreover, ultra-low-dose CT is already being used.[57,58] Therefore, low-dose CT should begin to be evaluated for assessment of other structures, such as the appendix, pancreas and sinuses, among others.

Even with the advent of MRI, CT remains the gold standard for diagnosing bone fractures.[25-27] Therefore, regarding evaluation of bone fractures, we believe that further studies are needed to assess the use of ultra-low-dose CT, which so far has only been analyzed by Konda et al.[28]

Ultra-low-dose CT uses a radiation dose similar to that of radiography and, consequently, further reduces the incidence of malignant neoplasms caused by standard-dose CT. Today, standard-dose CT is the cause of 1.5-2% of cases of malignant neoplasms.[1,6] This proportion is higher among children under 15 years old,[1,12,28] and even more so among children younger than 5 years.[6] Moreover, use of ultra-low-dose CT implies lower spending on medications and CT tubes. It would lead to increased quality of life for this population, over the long term.

However, as quoted by Lee,[19,39] only 9%-16% of doctors are aware of the risk of malignant neoplasms caused by radiation. Furthermore, 75% of radiologists and on-call staff in emergency departments underestimate the radiation dose of CT, and 91% of emergency room doctors do not know that CT increases the risk of cancer throughout life. Added to this is the fact that more than 90% of patients are not informed about the dangers of radiation before they undergo CT.[19,39] Therefore, it is extremely necessary to inform both healthcare professionals and patients about the risks of radiation and the ways in which its use in CT can be improved.

CONCLUSION

According to the results from this systematic review and meta-analysis, it can be suggested that, in evaluating trauma victims (cases due to falls, traffic accidents, etc.) and for patients undergoing tomographic monitoring of fractures, low-dose CT should

be used within clinical practice. This will reduce the radiation dose delivered to patients while maintaining the rate of fracture detection, in addition to reducing costs. Through this, it will be possible to maintain the quality of fracture diagnosis, while still avoiding complications of misdiagnosis, such as chronic arthritis, painful non-union or osteonecrosis. A decrease in CT radiation exposure is required, but image quality needs to be maintained for diagnostic accuracy.

It should be taken into account that, in our review, studies using multislice computed tomography devices with between 6 and 320 channels were evaluated, as there were no studies on other devices (helical or multislice with fewer channels) of sufficient quality for their inclusion. Evaluation of low-dose CT in patients with metallic structures was not possible since all the studies examined had excluded patients presenting metallic components (nails, screws, prostheses, etc.), from their selection of patients.

REFERENCES

1. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. N Engl J Med. 2007;357(22):2277-84. PMID: 18046031; https://doi.org/10.1056/NEJMra072149.

2. Brisco J, Fuller K, Lee N, Andrew D. Cone beam computed tomography for imaging orbital trauma--image quality and radiation dose compared with conventional multislice computed tomography. Br J Oral Maxillofac Surg. 2014;52(1):76-80. PMID: 24139635; https://doi.org/10.1016/j.bjoms.2013.09.011.

3. Kloth JK, Rickert M, Gotterbarm T, et al. Pelvic X-ray examinations in follow-up of hip arthroplasty or femoral osteosynthesis--dose reduction and quality criteria. Eur J Radiol. 2015;84:915-20. PMID: 25715664; https://doi.org/10.1016/j.ejrad.2015.02.001.

4. Garcia-Sanchez AJ, Garcia Angosto E, Llor JL, Serna Berna A, Ramos D. Machine Learning Techniques Applied to Dose Prediction in Computed Tomography Tests. Sensors (Basel). 2019;19(23):5116. PMID: 31766708; https://doi.org/10.3390/s19235116.

5. Alshamari M, Geijer M, Norrman E, Geijer H. Low-dose computed tomography of the lumbar spine: a phantom study on imaging parameters and image quality. Acta Radiol. 2014;55(7):824-32. PMID: 24215904; https://doi.org/10.1177/0284185113509615.

6. Banerjee P, Thomas M. CT scans to exclude spine fractures in children after negative radiographs may lead to increase in future cancer risk. Eur J Orthop Surg Traumatol. 2019;29(5):983-8. PMID: 30941632; https://doi.org/10.1007/s00590-019-02396-5.

7. Tien HC, Tremblay LN, Rizoli SB, et al. Radiation exposure from diagnostic imaging in severely injured trauma patients. J Trauma. 2007;62(1):151-6. PMID: 17215747; https://doi.org/10.1097/TA.0b013e31802d9700.

8. Moritz JD, Hoffmann B, Sehr D, et al. Evaluation of ultra-low dose CT in the diagnosis of pediatric-like fractures using an experimental animal study. Korean J Radiol. 2012;13(2):165-73. PMID: 22438683; https://doi.org/10.3348/kjr.2012.13.2.165.

9. Mansfield C, Ali S, Komperda K, Zhao H, Rehman S. Optimizing Radiation Dose in Computed Tomography of Articular Fractures. J Orthop Trauma. 2017;31(8):401-6. PMID: 28394843; https://doi.org/10.1097/BOT.0000000000000861.

10. Sollmann N, Mei K, Hedderich DM, et al. Multi-detector CT imaging: impact of virtual tube current reduction and sparse sampling on detection of vertebral fractures. Eur Radiol. 2019;29(7):3606-16. PMID: 30903337; https://doi.org/10.1007/s00330-019-06090-2.

11. Kim SJ, Bista AB, Min YG, et al. Usefulness of low dose chest CT for initial evaluation of blunt chest trauma [published correction appears in Medicine (Baltimore). 2017;96(23):e7234]. Medicine (Baltimore). 2017;96(2):e5888. PMID: 28079832; https://doi.org/10.1097/MD.0000000000005888.

12. Lemburg SP, Peters SA, Roggenland D, Nicolas V, Heyer CM. Cumulative effective dose associated with radiography and CT of adolescents with spinal injuries. AJR Am J Roentgenol. 2010;195(6):1411-7. PMID: 21098203; https://doi.org/10.2214/AJR.10.4616.

13. Rozema R, Doff MH, van Ooijen PM, et al. Diagnostic reliability of low dose multidetector CT and cone beam CT in maxillofacial trauma- an experimental blinded and randomized study. Dentomaxillofac Radiol. 2018;47(8):20170423. PMID: 29745761; https://doi.org/10.1259/dmfr.20170423.

14. Ippolito D, Besostri V, Bonaffini PA, et al. Diagnostic value of whole-body low-dose computed tomography (WBLDCT) in bone lesions detection in patients with multiple myeloma (MM). Eur J Radiol. 2013;82(12):2322-7. PMID: 24074647; https://doi.org/10.1016/j.ejrad.2013.08.036.

15. Widmann G, Juranek D, Waldenberger F, et al. Influence of Ultra-Low-Dose and Iterative Reconstructions on the Visualization of Orbital Soft Tissues on Maxillofacial CT. AJNR Am J Neuroradiol. 2017;38(8):1630-5. PMID: 28596194; https://doi.org/10.3174/ajnr.A5239.

16. Jin L, Ge X, Lu F, et al. Low-dose CT examination for rib fracture evaluation: A pilot study. Medicine (Baltimore). 2018;97(30):e11624. PMID: 30045304; https://doi.org/10.1097/MD.0000000000011624.

17. Lee SH, Yun SJ, Kim DH, et al. Diagnostic usefulness of low-dose lumbar multi-detector CT with iterative reconstruction in trauma patients: a comparison with standard-dose CT. Br J Radiol. 2017;90(1077):20170181. PMID: 28707527; https://doi.org/10.1259/bjr.20170181.

18. Lee SH, Yun SJ, Jo HH, Song JG. Diagnosis of lumbar spinal fractures in emergency department: low-dose versus standard-dose CT using model-based iterative reconstruction. Clin Imaging. 2018;50:216-22. PMID: 29677654; https://doi.org/10.1016/j.clinimag.2018.04.007.

19. Lee RK, Chu WC, Graham CA, Rainer TH, Ahuja AT. Knowledge of radiation exposure in common radiological investigations: a comparison between radiologists and non-radiologists. Emerg Med J. 2012;29(4):306-8. PMID: 21873321; https://doi.org/10.1136/emermed-2011-200481.

20. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet. 2012;380(9840):499-505. PMID: 22681860; https://doi.org/10.1016/S0140-6736(12)60815-0.

21. Andresz S, Morgan J, Croüail P, Vermeersch F. Conclusions and recommendations from the 17th Workshop of the European ALARA Network 'ALARA in emergency exposure situations'. J Radiol Prot. 2018;38(1):434-9. PMID: 29339579; https://doi.org/10.1088/1361-6498/aaa86b.

22. Kocyigit A, Serinken M, Ceven Z, et al. A strategy to optimize CT use in children with mild blunt head trauma utilizing clinical risk stratification; could we improve CT use in children with mild head injury? Clin Imaging. 2014;38(3):236-40. PMID: 24444707; https://doi.org/10.1016/j.clinimag.2013.12.004.

23. Kahn J, Kaul D, Böning G, et al. Quality and Dose Optimized CT Trauma Protocol - Recommendation from a University Level-I Trauma Center. Qualitäts- und dosisoptimiertes CT-Polytraumaprotokoll – Empfehlung eines universitären Level-I Traumazentrums. Rofo. 2017;189(9):844-54. PMID: 28651263; https://doi.org/10.1055/s-0043-108996.

24. Kim PK, Zhu X, Houseknecht E, et al. Effective radiation dose from radiologic studies in pediatric trauma patients. World J Surg. 2005;29(12):1557-62. PMID: 16331342; https://doi.org/10.1007/s00268-005-0106-x.

25. Duane TM, Mayglothling J, Wilson SP, et al. National Emergency X-Radiography Utilization Study criteria is inadequate to rule out fracture after significant blunt trauma compared with computed tomography. J Trauma. 2011;70(4):829-31. PMID: 21610391; https://doi.org/10.1097/TA.0b013e31820ea6b3.

26. Haapamäki VV, Kiuru MJ, Mustonen AO, Koskinen SK. Multidetector computed tomography in acute joint fractures. Acta Radiol. 2005;46(6):587-98. PMID: 16334840; https://doi.org/10.1080/02841850510021634.

27. Konda SR, Goch AM, Haglin J, Egol KA. Ultralow-Dose CT (REDUCTION Protocol) for Extremity Fracture Evaluation Is as Safe and Effective as Conventional CT: An Evaluation of Quality Outcomes. J Orthop Trauma. 2018;32(5):216-222. PMID: 29401094; https://doi.org/10.1097/BOT.0000000000001137.

28. Konda SR, Goch AM, Leucht P, et al. The use of ultra-low-dose CT scans for the evaluation of limb fractures: is the reduced effective dose using CT in orthopaedic injury (REDUCTION) protocol effective? Bone Joint J. 2016;98-B(12):1668-73. PMID: 27909130; https://doi.org/10.1302/0301-620X.98B12.BJJ-2016-0336.R1.

29. Zacchino M, Bonaffini PA, Corso A, et al. Inter-observer agreement for the evaluation of bone involvement on Whole Body Low Dose Computed Tomography (WBLDCT) in Multiple Myeloma (MM). Eur Radiol. 2015;25(11):3382-9. PMID: 25987427; https://doi.org/10.1007/s00330-015-3733-0.

30. Alshamari M, Geijer M, Norrman E, et al. Low dose CT of the lumbar spine compared with radiography: a study on image quality with implications for clinical practice. Acta Radiol. 2016;57(5):602-11. PMID: 26221055; https://doi.org/10.1177/0284185115595667.

31. Finkenstaedt T, Morsbach F, Calcagni M, et al. Metallic artifacts from internal scaphoid fracture fixation screws: comparison between C-arm flat-panel, cone-beam, and multidetector computed tomography. Invest Radiol. 2014;49(8):532-9. PMID: 24691141; https://doi.org/10.1097/RLI.0000000000000052.

32. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med. 2011;155(8):529-536. PMID: 22007046; https://doi.org/10.7326/0003-4819-155-8-201110180-00009.

33. Margulis AV, Pladevall M, Riera-Guardia N, et al. Quality assessment of observational studies in a drug-safety systematic review, comparison of two tools: the Newcastle-Ottawa Scale and the RTI item bank. Clin Epidemiol. 2014;6:359-68. PMID: 25336990; https://doi.org/10.2147/CLEP.S66677.

34. Viswanathan M, Berkman ND. Development of the RTI item bank on risk of bias and precision of observational studies. J Clin Epidemiol. 2012;65(2):163-78. PMID: 21959223; https://doi.org/10.1016/j.jclinepi.2011.05.008.

35. Mulkens TH, Marchal P, Daineffe S, et al. Comparison of low-dose with standard-dose multidetector CT in cervical spine trauma. AJNR Am J Neuroradiol. 2007;28(8):1444-50. PMID: 17846188; https://doi.org/10.3174/ajnr.A0608.

36. Yi JW, Park HJ, Lee SY, et al. Radiation dose reduction in multidetector CT in fracture evaluation. Br J Radiol. 2017;90(1077):20170240. PMID: 28707536; https://doi.org/10.1259/bjr.20170240.

37. Arruda LRP, de Campos Silva MA, Malerba FG, de Castro Fernandes M, Matsumoto FMTMH. Fraturas expostas: estudo epidemiológico e prospectivo. Acta Ortopédica Brasileira 2009;17:326-30. https://doi.org/10.1590/S1413-78522009000600002.

38. Soares DS, Mello LM, Silva AS, Martinez EZ, Nunes AA. Fraturas de fêmur em idosos no Brasil: análise espaço-temporal de 2008 a 2012 [Femoral fractures in elderly Brazilians: a spatial and temporal analysis from 2008 to 2012]. Cad Saude Publica. 2014;30(12):2669-78. PMID: 26247995; https://doi.org/10.1590/0102-311X00218113.

39. Lee CI, Haims AH, Monico EP, Brink JA, Forman HP. Diagnostic CT scans: assessment of patient, physician, and radiologist awareness of radiation dose and possible risks. Radiology. 2004;231(2):393-8. PMID: 15031431; https://doi.org/10.1148/radiol.2312030767.

40. Kim PK, Gracias VH, Maidment AD, et al. Cumulative radiation dose caused by radiologic studies in critically ill trauma patients. J Trauma. 2004;57(3):510-4. PMID: 15454795; https://doi.org/10.1097/01.ta.0000141028.97753.67.

41. Salottolo K, Bar-Or R, Fleishman M, et al. Current utilization and radiation dose from computed tomography in patients with trauma. Crit Care Med. 2009;37(4):1336-40. PMID: 19242327; https://doi.org/10.1097/CCM.0b013e31819d6739.

42. Neubauer J, Benndorf M, Reidelbach C, et al. Comparison of Diagnostic Accuracy of Radiation Dose-Equivalent Radiography, Multidetector Computed Tomography and Cone Beam Computed Tomography for Fractures of Adult Cadaveric Wrists. PLoS One. 2016;11(10):e0164859. PMID: 27788215; https://doi.org/10.1371/journal.pone.0164859.

43. Stuhlfaut JW, Lucey BC, Varghese JC, Soto JA. Blunt abdominal trauma: utility of 5-minute delayed CT with a reduced radiation dose. Radiology. 2006;238(2):473-9. PMID: 16436812; https://doi.org/10.1148/radiol.2382042096.

44. Richards PJ, George J. Diagnostic CT radiation and cancer induction. Skeletal Radiol. 2010;39(5):421-4. PMID: 19953245; https://doi.org/10.1007/s00256-009-0819-2.

45. Wirth S, Euler E, Linsenmaier U, et al. C-arm-based mobile computed tomography: a comparison with established imaging on the basis of simulated treatments of talus neck fractures in a cadaveric study. Comput Aided Surg. 2004;9(1-2):27-38. PMID: 15792934; https://doi.org/10.3109/10929080400006309.

46. Kopp FK, Holzapfel K, Baum T, et al. Effect of Low-Dose MDCT and Iterative Reconstruction on Trabecular Bone Microstructure Assessment. PLoS One. 2016;11(7):e0159903. PMID: 27447827; https://doi.org/10.1371/journal.pone.0159903.

47. Lessmann N, van Ginneken B, de Jong PA, Išgum I. Iterative fully convolutional neural networks for automatic vertebra segmentation and identification. Med Image Anal. 2019;53:142-55. PMID: 30771712; https://doi.org/10.1016/j.media.2019.02.005.

48. Hultman KL, Vaidya R, Malkawi I, Carlson JB, Wynberg JB. Accuracy of Low Dose Computed Tomography Scanogram for Measurement of Femoral Version after Locked Intramedullary Nailing. Int Orthop. 2016;40(9):1955-60. PMID: 26572887; https://doi.org/10.1007/s00264-015-3040-z.

49. Pache G, Bulla S, Baumann T, et al. Dose reduction does not affect detection of bone marrow lesions with dual-energy CT virtual noncalcium technique. Acad Radiol. 2012;19(12):1539-45. PMID: 23020888; https://doi.org/10.1016/j.acra.2012.08.006.

50. Crawley T, Meagher T, Wainwright A. Good practice or good luck? Prolonged CT tube life and low dose protocols. Clin Radiol. 2002;57(5):431. PMID: 12014946; https://doi.org/10.1053/crad.2002.0984.

51. McNitt-Gray MF. AAPM/RSNA Physics Tutorial for Residents: Topics in CT. Radiation dose in CT. Radiographics. 2002;22(6):1541-53. PMID: 12432127; https://doi.org/10.1148/rg.226025128.

52. Afadzi M, Fosså K, Andersen HK, Aaløkken TM, Martinsen ACT. Image Quality Measured From Ultra-Low Dose Chest Computed Tomography Examination Protocols Using 6 Different Iterative Reconstructions From 4 Vendors, a Phantom Study. J Comput Assist Tomogr. 2020;44(1):95-101. PMID: 31939889; https://doi.org/10.1097/RCT.0000000000000947.

53. Singh R, Digumarthy SR, Muse VV, et al. Image Quality and Lesion Detection on Deep Learning Reconstruction and Iterative Reconstruction of Submillisievert Chest and Abdominal CT. AJR Am J Roentgenol. 2020;214(3):566-73. PMID: 31967501; https://doi.org/10.2214/AJR.19.21809.

54. Mookiah MRK, Baum T, Mei K, et al. Effect of radiation dose reduction on texture measures of trabecular bone microstructure: an in vitro study. J Bone Miner Metab. 2018;36(3):323-35. PMID: 28389933; https://doi.org/10.1007/s00774-017-0836-5.

55. Ruchalski K, Gutierrez A, Genshaft S, Abtin F, Suh R. The evidence for low-dose CT screening of lung cancer. Clin Imaging. 2016;40(2):288-95. PMID: 26362352; https://doi.org/10.1016/j.clinimag.2015.07.001.

56. Raymakers AJN, Mayo J, Lam S, et al. Cost-Effectiveness Analyses of Lung Cancer Screening Strategies Using Low-Dose Computed Tomography: a Systematic Review. Appl Health Econ Health Policy. 2016;14(4):409-18. PMID: 26873091; https://doi.org/10.1007/s40258-016-0226-5.

57. Rob S, Bryant T, Wilson I, Somani BK. Ultra-low-dose, low-dose, and standard-dose CT of the kidney, ureters, and bladder: is there a difference? Results from a systematic review of the literature. Clin Radiol. 2017;72(1):11-5. PMID: 27810168; https://doi.org/10.1016/j.crad.2016.10.005.

58. Sui X, Meinel FG, Song W, et al. Detection and size measurements of pulmonary nodules in ultra-low-dose CT with iterative reconstruction compared to low dose CT. Eur J Radiol. 2016;85(3):564-70. PMID: 26860668; https://doi.org/10.1016/j.ejrad.2015.12.013.

Address for correspondence:

Márcio Luís Duarte

R. Napoleão de Barros, 865

Vila Clementino — São Paulo (SP) — Brasil

CEP 04024-002

Tel. (+55 11) 5576-4848

E-mail: marcioluisduarte@gmail.com