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Background: Computerized tomographic scans are routinely obtained to evaluate a number of musculoskeletal conditions. However, since computerized tomographic scans expose patients to the greatest amounts of radiation of all imaging modalities, the physician must be cognizant of the effective doses of radiation that are administered. This investigation was performed to quantify the effective doses of computerized tomographic scans that are performed for various musculoskeletal applications.

Methods: The digital imaging archive of a single institution was retrospectively reviewed to identify helical computerized tomographic scans that were completed to visualize the extremities or spine. Imaging parameters were recorded for each examination, and dosimetry calculator software was used to calculate the effective dose values according to a modified protocol derived from publication SR250 of the National Radiological Protection Board of the United Kingdom. Computerized tomographic scans of the chest, abdomen, and pelvis were also collected, and the effective doses were compared with those reported by prior groups in order to validate the results of the current study.

Results: The mean effective doses for computerized tomographic scans of the chest, abdomen, and pelvis (5.27, 4.95, and 4.85 mSv, respectively) were consistent with those of previous investigations. The highest mean effective doses were recorded for studies evaluating the spine (4.36, 17.99, and 19.15 mSv for the cervical, thoracic, and lumbar spines, respectively). In the upper extremity, the effective dose of a computerized tomographic scan of the shoulder (2.06 mSv) was higher than those of the elbow (0.14 mSv) and wrist (0.03 mSv). Similarly, the effective dose of a hip scan (3.09 mSv) was significantly higher than those observed with knee (0.16 mSv) and ankle (0.07 mSv) scans.

Conclusions: Computerized tomographic scans of the axial and appendicular skeleton are associated with substantially elevated radiation exposures, but the effective dose declines substantially for anatomic structures that are further away from the torso.

Over the past decade, the increasing need for imaging studies that not only have excellent resolution but also may be acquired in an expeditious fashion has yielded important advances in computerized tomography technology. For example, the development of helical and multidetector computerized tomography devices has drastically reduced scanning times and increased the efficiency of the imaging process, which is particularly advantageous in the assessment of uncooperative or medically unstable patients. These innovations have undoubtedly contributed to the current popularity of computerized tomography, which is reflected by the more than sixty-two million scans that are obtained each year in the United States alone[1].

Although computerized tomography is clearly one of the most expedient three-dimensional imaging modalities available, these studies are not without their risks. Computerized tomography accounts for <5% of all radiographic examinations but contributes up to 40% of the cumulative radiation

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dose conferred by diagnostic imaging[2]. Not surprisingly, the relatively high doses of radiation that patients receive as a result of computerized tomographic scans have raised concerns regarding the oncogenic potential of this type of exposure.

Previous investigations have demonstrated that exposure to even low doses of ionizing radiation may increase the risk for the development of cancer[3-8]. Most of the quantitative information that has been used to elucidate the hazards of radiation was provided by epidemiologic reports that followed individuals who survived the atomic bombs in Japan. Those longitudinal studies identified a significant increase in the prevalence of radiation-induced malignancies, such as leukemia and solid tumors, among those who received whole-body doses of radiation ranging from 5 to 150 mSv; the average dose absorbed by that cohort was 40 mSv[3-6]. In a review of 400,000 workers in the nuclear industry who were exposed to an average whole-body dose of 20 mSv, subjects who received doses between 5 and 150 mSv were also more likely to be diagnosed with cancer[7,8].

The issue of iatrogenic radiation exposure was initially raised in 1991 by a national survey conducted in the United Kingdom by the National Radiological Protection Board and reported in publication SR250, which described estimates of the doses administered to adults during the course of common computerized tomographic procedures[9]. Since then, several groups have reported the radiation doses generated by frequently performed nonorthopaedic computerized tomographic examinations including those of the head[10], neck[11], chest[12-14], abdomen, and pelvis[15-18]. Collectively, these data suggest that the radiation doses delivered by conventional computerized tomographic studies may predispose patients to the development of malignant lesions[19].

Several distinct measures have been used to quantify the radiation exposures generated by computerized tomographic scans. Because the various tissues of the body exhibit different radiosensitivities and most computerized tomographic scans typically expose the patient to nonuniform, partial-body irradiation, the overall risk attributable to radiation exposure is dependent on the specific dose absorbed by each organ. Originally defined by Jacobi in 1975, the effective dose represents a weighted, whole-body estimate of an individual's radiation exposure that considers the specific radiosensitivities of the irradiated organs[20,21]. The effective dose remains one of the most prevalent methods for defining the exposures that patients receive from diagnostic examinations. It is used not only to establish the risk of radiation-induced carcinogenesis but also to allow for the direct comparison of the amounts of ionizing radiation that are produced by different imaging modalities.

While the radiation exposures associated with nonorthopaedic computerized tomographic scans have already been described in the literature, there continues to be a paucity of studies that have calculated the effective dose derived from computerized tomographic imaging of the musculoskeletal system[16,18,22-25]. The purpose of the present investigation was to quantify the effective dose of radiation associated with computerized tomographic scans of musculoskeletal structures including the spine and extremities. These findings are clearly of interest both to orthopaedic surgeons who must weigh the diagnostic benefits of these studies against their potential risks as well as to their patients who must be informed about the health hazards they are subjected to as a result of these commonly performed imaging procedures.

Materials and Methods

Inclusion Criteria for Computerized Tomographic Examinations

This study was approved by our institution's Human Investigations Committee. The computerized tomographic examinations included in the analysis were identified from a single digital imaging archive system (Synapse/PACS; Fujifilm USA, Stamford, Connecticut) and were limited to noncontrast helical scans of specific anatomic regions (shoulder, elbow, wrist and hand, hip, knee, foot and ankle, and cervical, thoracic, and lumbar spine) that were performed in adults with Lightspeed 16, Qx/I, or VCT scanners (GE Medical Systems, Milwaukee, Wisconsin) between January 2007 and January 2008. After it was confirmed that standard radiographic techniques and protocols had been used for imaging the regions of interest, an appropriate sample of studies (twenty) was randomly selected from this retrospective review for each anatomic region of interest. The scan range for all joints in this study was consistent between examinations of the same joint and did not encompass an entire limb. A consistent scan interval encompassing the area of interest was verified for each scan prior to its inclusion in our investigation.

Calculation of Effective Doses

The effective dose was calculated for standard computerized tomographic examinations of the upper and lower extremities as well as the cervical, thoracic, and lumbar spines. Computerized tomographic scans of the elbow were performed with use of one of two techniques, both of which are routinely utilized by our radiology department; depending on the clinical scenario, the joint was either placed adjacent to the trunk of the patient or held above the head away from the torso. In order to validate our methodology, the effective dose of computerized tomographic studies of the chest, abdomen, and pelvis were also estimated and compared with the corresponding values previously reported in the literature[14-16,18].

To take into account the differential radiosensitivities of various organs (ranging from gonads to bone), the absorbed dose of radiation (H_T) administered to each anatomic structure must first be determined. These values are modified on the basis of certain tissue-weighting factors (W_T) recommended by the International Commission on Radiological Protection (ICRP) Publication 60, which factor in the relative contributions of specific organ systems to the overall radiation risk in patients who have uniform whole-body exposure[20] (Table I). As depicted in the equation below, the effective dose (ED) represents a weighted average of organ doses (H_T) adjusted according to these tissue-weighting factors (W_T):

$$\text{Equation 1} \quad ED = \Sigma_T (W_T \times H_T)$$

TABLE I Tissue-Weighting Factors Recommended by the International Commission on Radiological Protection Publication 60

Tissue or Organ	Tissue-Weighting Factor (W_T)
Gonads	0.20
Bone marrow (red), colon, lung, and stomach	0.12
Bladder, breast, liver, esophagus, and thyroid	0.05
Skin and bone surface	0.01
Remainder organs	0.05

Calculation of the Organ-Specific Dose of Absorbed Radiation (H_T)

While the ideal technique for measuring H_T values is by using organ-specific thermoluminescent dosimeters, this approach was not feasible in the present retrospective study. A number of alternative approaches have also been developed to quantify these doses, most of which are based on standardized patient models, or so-called phantoms.

In 1991, the National Radiological Protection Board of the United Kingdom sought to determine organ-specific H_T by performing computerized tomographic simulations based on a mathematical anthropomorphic phantom[9]. In these computerized Monte Carlo simulations, the radiation doses for the organ in each imaged section were calculated and used to assess the total absorbed organ dose. The National Radiological Protection Board provided normalized organ dose coefficients (f_{organ}) for the purpose of estimating organ-specific H_T based on overall region-specific radiation exposure[26]; these data have been incorporated by multiple software programs. In this study, the computerized tomography patient dosimetry calculator software (CTDosimetry.xls, ImPACT CT Patient Dosimetry Calculator, version 0.99x; Imaging Performance Assessment of CT Scanners; St. George's Hospital, Tooting, London, United Kingdom) was utilized to estimate H_T.

The computerized tomography dose index refers to the amount of radiation generated by a single image, which is influenced by several variables such as the tube current (mA), peak tube voltage (kVp), scanning time, and the technical specifications of the scanner[1]. Another descriptor that is frequently used to characterize the radiation dose is computerized tomography dose index by volume (CTDIvol), which also considers the pitch of the scan (i.e., the degree of overlap between adjacent computerized tomography slices). Thus, the H_T for each organ within the scanned region of a given computerized tomographic study was calculated by integrating the CTDIvol data with the normalized organ dose coefficients (f_{organ}) issued by the National Radiological Protection Board (Equation 2). The H_T of all of the organs was multiplied by the appropriate tissue-weighting factors (W_T) to derive the effective dose (Equation 1).

TABLE II Exposure Data for Computerized Tomographic Scans Evaluated

Scan	No. of Scans	CTDIvol* *(mGy)*	Dose Length Product* *(mGy-cm)*	Tube Voltage *(kVp)*	Tube Current* *(mA)*
Chest, abdomen, and pelvis					
Chest	20	20.16 ± 6.67	659.89 ± 190.50	120.00	466.6 ± 104.23
Abdomen	20	17.08 ± 5.05	468.27 ± 141.92	120.00	475.3 ± 149.93
Pelvis	20	23.34 ± 9.83	648.66 ± 278.61	120.00	409.95 ± 130.12
Upper extremity					
Shoulder	20	19.49 ± 13.77	315.96 ± 211.46	121.00	365.05 ± 176.02
Elbow (arm only)	20	21.52 ± 23.83	293.13 ± 311.45	122.00	179.35 ± 89.16
Elbow (body)	20	32.95 ± 23.64	495.24 ± 400.70	120.00	259.75 ± 135.26
Wrist and hand	20	14.41 ± 15.52	136.73 ± 134.30	120.00	129.2 ± 110.32
Lower extremity					
Hip	20	19.83 ± 7.67	422.50 ± 174.05	120.00	323.15 ± 109.47
Knee	20	18.39 ± 14.43	359.90 ± 288.32	121.00	143.95 ± 86.33
Ankle and foot (unilateral)	20	17.88 ± 13.39	310.07 ± 209.62	120.00	143.00 ± 91.05
Spine					
Cervical	20	64.17 ± 29.04	1413.51 ± 831.18	140.00	483.05 ± 158.44
Thoracic	20	64.39 ± 22.23	2171.10 ± 804.95	140.00	286.9 ± 90.71
Lumbar	20	66.53 ± 21.56	1701.34 ± 688.97	140.00	304.25 ± 100.87

*The values are given as the mean and the standard deviation.

TABLE III Effective Doses of Computerized Tomographic Examinations and the Number of Equivalent Conventional Chest Radiographs

Scan	No. of Scans	Effective Dose* (*mSv*)	No. of Conventional Chest Radiographs Needed for Equivalent Dose†
Chest, abdomen, and pelvis			
Chest	20	5.27 ± 1.68	65.88
Abdomen	20	4.95 ± 1.40	61.88
Pelvis	20	4.85 ± 1.74	60.63
Upper extremity			
Shoulder	20	2.06 ± 1.52	25.75
Elbow (arm only)	20	0.14 ± 0.22	1.75
Elbow (body)	20	8.35 ± 5.88	104.38
Wrist and hand	20	0.03 ± 0.03	0.38
Lower extremity			
Hip	20	3.09 ± 1.37	38.63
Knee	20	0.16 ± 0.12	2.00
Ankle and foot (unilateral)	20	0.07 ± 0.05	0.88
Spine			
Cervical	20	4.36 ± 2.03	54.50
Thoracic	20	17.99 ± 6.12	224.88
Lumbar	20	19.15 ± 5.63	239.38

*The values are given as the mean and the standard deviation. †The effective dose of a conventional chest radiograph has been reported to be approximately 0.08 mSv[28].

$$\text{Equation 2} \quad H_T = \text{CTDIvol}\ \Sigma\ (f_{organ})$$

Study-Specific Calculations

For each computerized tomographic examination, the demographic data for the subject were recorded to ensure that suitable sex-specific phantoms had been selected that accounted for the position of reproductive structures and offered more accurate estimates of the radiation exposure of that individual. In addition to documenting the tube voltage (in kilovolts peak) and current (in milliamps), the CTDIvol (in milligray) and the dose length product (i.e., CTDIvol multiplied by the total scan range, which is expressed in milligray-centimeters) were also obtained from a standardized dose report supplied by the scanner.

The information was then input into the computerized tomography dosimetry spreadsheet, in which the CTDIvol, the manufacturer and model of the computerized tomographic scanner, voltage (in kilovolts), sex, as well as the start and end positions of each scan that served as the anatomic boundaries for the mathematical phantom were specified[9,26,27]. At that point, the software automatically quantified the H_T for each organ and merged these values with their corresponding tissue-weighting factors (W_T) to calculate the effective dose.

It should be noted that the organ dose coefficients provided by the National Radiological Protection Board were based on studies centered on the axial skeleton; for instance, these data sets only incorporated the proximal part of the femora in their measurements. Consequently, it was assumed that this anthropomorphic phantom may not be applicable to the middle and distal portions of the extremities so this protocol was modified for examinations of the elbow, wrist and hand, knee, and foot and ankle. For these scans, the organ doses to muscle, skin, bone surface, and red marrow were calculated, with use of the methods described above, for the proximal 10 cm of the femur. Proceeding under the assumption that these were the only organs irradiated during studies involving the distal part of the extremities, the appropriate weighting coefficients (Table I) were applied to estimate the effective dose for the proximal part of the femur; this value was extrapolated according to the total length of the extremity that was subjected to radiation to ascertain the effective dose of these types of scans.

Statistical Methods

Univariate analysis of variance was used to compare the effective dose, CTDIvol, dose length product, and milliamperes of the various scans of the upper extremity (i.e., shoulder, elbow, and wrist and hand) as well as those targeting the lower extremity (i.e., hip, knee, and foot and ankle); a post hoc Tukey test was performed to identify any significant differences among these two separate groups of examinations. Finally, a t test for independent samples was used to compare the values associated with dedicated scans of the thoracic and lumbar spine with those calculated for chest and abdominal studies, respectively. Significance was established at an alpha level of 0.05 ($p < 0.05$).

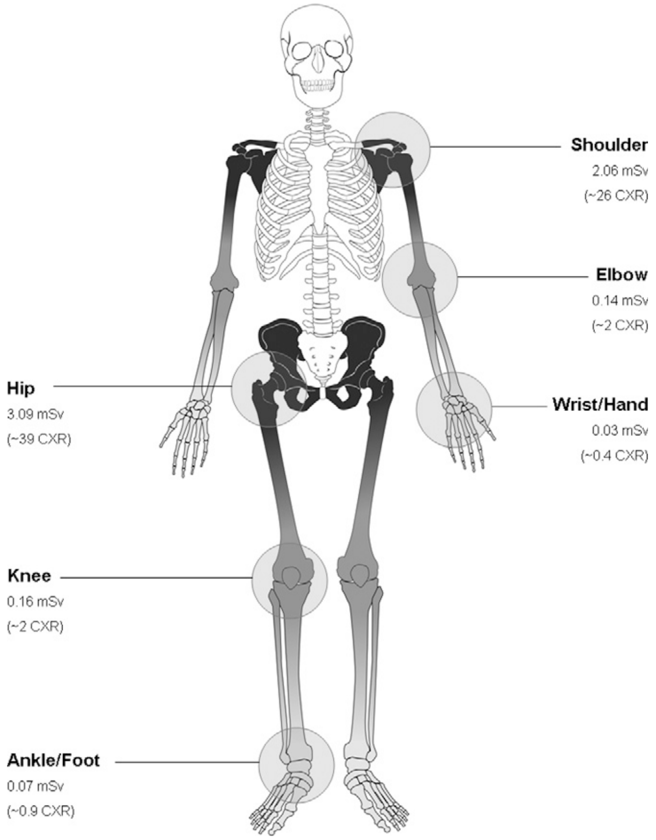

Fig. 1
Effective doses for computerized tomographic examinations of the extremities. CXR = number of conventional chest radiographs needed for equivalent dose.

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No external sources of funding or support were utilized in the production of this work.

Results

The exposure settings for the computerized tomographic examinations included in this study are listed in Table II. The effective doses calculated for these various scans are shown in Table III and in Figures 1 and 2. The mean effective doses for examinations of the chest (5.27 mSv), abdomen (4.95 mSv), and pelvis (4.85 mSv) were similar to those previously reported in the literature[28]. In an attempt to place the radiation exposures of computerized tomographic scans of the musculoskeletal system in proper perspective, Table III also depicts the number of conventional chest radiographs that would need to be ordered in order to subject the patient to an equivalent amount of radiation. The effective dose of a posteroanterior chest radiograph is known to be approximately 0.08 mSv[28], which is roughly equivalent to the background radiation absorbed during a round-trip airplane flight from New York to London[29]. Since chest radiographs are one of the most frequently obtained imaging studies, this quantity serves as a useful benchmark for evaluating the radiation risks inherent to other radiographic procedures.

In both the upper and lower extremities, the effective dose decreased as more distal structures were imaged. Univariate analysis of variance and post hoc Tukey testing revealed that an elbow study in which the joint is placed directly against the torso (mean, 8.35 mSv) yielded an effective dose that was not only significantly greater than that of a conventional elbow scan, in which the extremity is elevated above the head, but was also larger than the values calculated for computerized tomographic examinations of the shoulder and the wrist and hand ($p < 0.01$). Not surprisingly, a computerized tomographic scan of the shoulder (2.06 mSv) yielded a higher mean effective dose than did conventional elbow (0.14 mSv) and wrist and hand (0.03 mSv) procedures. Both the mean CTDIvol (32.95 compared with 14.41 mGy; $p = 0.02$) and the mean dose length product (495.24 compared with 136.73 mGy-cm; $p = 0.001$) were significantly higher for elbow scans in which the extremity was positioned adjacent to the body than the analogous quantities associated with wrist and hand examinations. The mean tube current measured during computerized tomographic imaging of the shoulder (365.05 mA) was also significantly greater than those generated by conventional studies of the elbow (179.35 mA; $p \leq 0.001$) and the wrist and hand (129.2 mA; $p < 0.00001$).

Similar results were also observed in the lower extremity, where the mean effective dose of hip scans (3.09 mSv) was

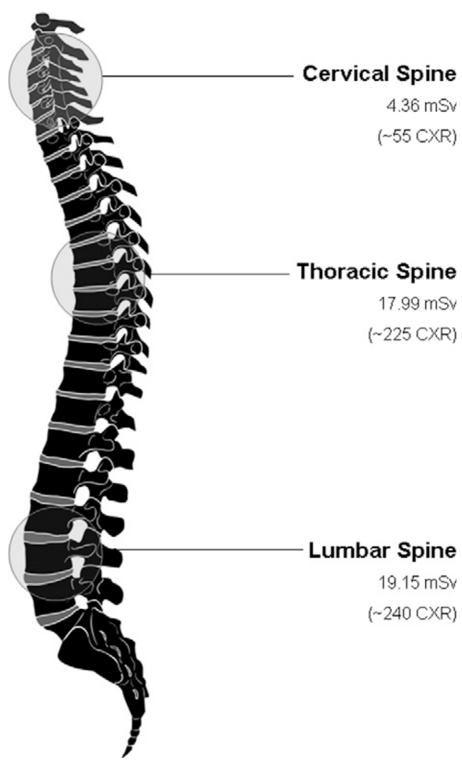

Fig. 2
Effective doses for computerized tomographic examinations of the spine. CXR = number of conventional chest radiographs needed for equivalent dose.

TABLE IV Approximate Whole-Body Doses of Radiation Associated with Societal Exposures*

Exposure	Approximate Mean Whole-Body Individual Dose (*mSv*)
Posteroanterior chest radiograph	0.08
Round-trip airplane flight from New York to London	0.1
Background dose due to natural radiation exposure in one calendar year	3
Dose (over a 70-yr period) to 0.5 million individuals in rural Ukraine in the vicinity of the Chernobyl accident	14
Radiation worker exposure limit in one year	20
Dose range over 20-block radius from a hypothetical nuclear terrorism incident	3 to 30
Exposure on International Space Station in one year	170
Atomic bomb survivors (LSS cohort)†	200

*Adapted from Brenner et al.[29]. †LSS = Life-Span Study.

significantly higher than those involving the knee (0.16 mSv; $p < 0.001$) or ankle (0.07 mSv; $p < 0.001$). Although no significant differences were detected between the CTDIvol and dose length product of the various lower extremity examinations, the mean tube current of a computerized tomographic study of the hip (323.15 mA) was shown to be significantly greater than those of knee (143.95 mA; $p < 0.00001$) and ankle studies (143.00 mA; $p < 0.005$).

In general, computerized tomographic scans of the spine generated greater amounts of radiation relative to examinations centered on the extremities. The mean effective dose values for the cervical, thoracic, and lumbar spines were 4.36, 17.99, and 19.15 mSv, respectively. Computerized tomographic scans of the thoracic spine demonstrated significantly elevated values in comparison with those of the chest with regard to the mean effective dose (17.99 and 5.27 mSv, respectively; $p < 0.01$), mean CTDIvol (64.38 and 20.16 mGy; $p < 0.01$), and mean dose length product (2171.10 and 659.89 mGy-cm; $p < 0.01$); conversely, the mean tube current of thoracic spine studies was actually lower than that of chest examinations (286.90 compared with 466.60 mA; $p < 0.01$). Likewise, the mean values for lumbar scans were also significantly higher than those estimated for abdominal examinations with regard to the effective dose (19.15 and 4.95 mSv, respectively; $p < 0.01$), CTDIvol (66.53 and 17.08 mGy; $p < 0.01$), and dose length product (1701.34 and 468.27 mGy-cm; $p < 0.01$), whereas the mean tube current of these dedicated spinal studies was significantly lower compared with the corresponding abdominal images (304.25 and 475.3 mA, respectively; $p < 0.01$).

Discussion

Computerized tomography has evolved into one of the most effective imaging modalities for assessing a wide range of musculoskeletal conditions[23,24,30]. Regardless of its obvious benefits for facilitating the diagnosis and treatment of pathologic lesions, these scans are known to subject individuals to the inherent risks of radiation exposure.

Lattanzi et al. previously demonstrated that the effective dose absorbed by cadaver specimens during computerized tomographic scans of the hip ranged from 1.9 to 7 mSv, with higher resolution images yielding greater amounts of radiation[23]; in a similar set of experiments, Henckel et al. estimated the effective dose for certain computerized tomographic sequences of the knee to be approximately 0.12 mSv[30]. Nevertheless, the specialized protocols used by those authors were designed to visualize hip and knee anatomy prior to total joint replacements and therefore may not be applicable to scans of the spine or other parts of the extremities. In the European literature, the effective dose for computerized tomographic imaging of the cervical, thoracic, and lumbar spine has been reported to be between 0.4 and 3.8, 1 and 16.8, and 0.8 and 8.6 mSv, respectively[18,22,31]. However, all of those values were derived from survey investigations of computerized tomography protocols and were not based on actual scans that had been performed. Thus, at this time, there continues to be a paucity of studies that have systematically evaluated the radiation doses that are generated by computerized tomographic scans of the spine or extremities.

Our findings indicate that the amounts of radiation administered to patients during these examinations diminish as the gantry is moved away from the torso. In the upper extremity, the mean effective dose declined from 2.06 mSv for the shoulder to 0.14 mSv and 0.03 mSv for the elbow and for the wrist and hand, respectively. A similar trend was observed in the lower extremity in that the mean effective dose progressively decreased as more distal structures were scanned (3.09, 0.16, and 0.07 mSv for the hip, knee, and ankle, respectively).

It is inevitable that anatomic structures in close proximity to the axial skeleton are also subjected to ionizing radiation during computerized tomographic studies of the proximal part of the extremities. For example, a computerized tomographic scan of the shoulder may irradiate the thyroid, lung parenchyma, or breast tissue, while a computerized tomographic examination of the hip may increase the exposures of several radiosensitive viscera in the pelvis, most notably the gonads. In contrast, with imaging of the distal part of the extremities, the x-ray beam generally penetrates only muscle, skin, cortical bone, and bone marrow, which are more resistant to the deleterious effects of radiation than the other organs located adjacent to the axial skeleton. Given the disparity between the effective dose produced by the two different methods for visualizing the elbow, it appears as if the manner in which an extremity is positioned during a computerized tomographic examination may also affect the amount of radiation that is absorbed; placement of the elbow directly against the trunk likely resulted in greater irradiation of the liver, lungs, and intestines.

According to our analysis, the mean effective dose of thoracic (17.99 mSv) and lumbar spine studies (19.15 mSv) were significantly higher than those of chest (5.27 mSv) and abdominal (4.95 mSv) scans, confirming that computerized tomographic examinations of the spinal column deliver markedly increased doses of radiation. Even though multiple organs in the thoracic and abdominal cavities are irradiated with both types of studies, spinal imaging requires different exposure settings (e.g., CTDIvol, dose length product, and tube voltage) in order to depict the osseous and soft-tissue anatomy of the thoracolumbar spine in sufficient detail. This may be of particular importance when serial computerized tomographic examinations of the spine are indicated postoperatively or during clinical follow-up, since such imaging would subject radiosensitive tissues, such as the stomach, intestines, liver, and other abdominal parenchyma, to repeated radiation exposure. Despite the lower radiation doses conferred by conventional chest and abdominal computerized tomography protocols, it is still unclear whether these studies provide the same diagnostic information to clinicians as dedicated examinations of the spine; this issue clearly warrants further investigation because of the potential for reducing the cumulative radiation exposure of patients undergoing these scans.

On the basis of the data collected from survivors of the atomic bombs in Japan, it has been suggested that a mean dose of radiation as low as 34 mSv may result in a significant increase in the mortality rate secondary to the formation of solid tumors[3,6]. In addition to the adverse effects of a single, large quantity of ionizing radiation, repeated exposures over time may also be associated with a greater prevalence of fatal soft-tissue and blood-borne malignancies[7,8,32]. In support of these findings, other epidemiologic investigations have concluded that an acute exposure to 10 to 50 mSv or cumulative doses totaling between 50 and 100 mSv may predispose patients to the development of certain cancers[29] (Table IV).

The effective dose values reported in this study provide further evidence that the radiation exposures produced by computerized tomographic examinations of the axial and appendicular skeleton are associated with a measurable risk, particularly when they involve the spine or the proximal aspect of the extremities. For instance, the mean effective dose of a single computerized tomographic scan of the lumbar spine was determined to be 19.15 mSv, which corresponds to the amount of radiation imparted by approximately 240 chest radiographs. Furthermore, the effective dose of a hip or shoulder examination is nearly equivalent to the total amount of annual background radiation from all other sources.

Certainly, several strategies may be employed to minimize the radiation exposure to patients during computerized tomographic examinations, including the use of lead aprons on nonimaged portions of the patient as well as modified imaging parameters (tube current and pitch) and more limited scan ranges that could result in reduced radiation exposures. Ultimately, it is incumbent on the practitioner ordering any of these computerized tomographic scans to be cognizant of their hazards, which must be weighed against their clinical utility when considering whether these studies are truly indicated.

In comparison, the amounts of radiation emitted during computerized tomographic examinations of more distal structures (i.e., the elbow, hand and wrist, knee, and foot and ankle) are essentially negligible. In fact, an individual may be subjected to more radiation as a result of a routine posteroanterior chest radiograph (0.08 mSv) than with a computerized tomographic examination of the wrist (0.03 mSv) or ankle (0.07 mSv). In most patients, it is expected that the diagnostic information afforded by these computerized tomographic scans would supersede any concerns about excessive radiation exposure.

Although we know of no large-scale epidemiologic reports that have attempted to quantify the cancer risks associated with computerized tomographic examinations, Brenner et al., in a study published in 2001, estimated the lifetime risks of cancer-related mortality attributable to the radiation exposure from a computerized tomographic scan in a one-year-old child are 0.18% (abdominal) and 0.07% (head)—an order of magnitude higher than those for adults[33]. The authors attributed these findings to the increased radiosensitivity of children to ionizing radiation along with increased absorbed organ doses due to the reduced body dimensions in pediatric patients. We know of no current reports on the mortality risks attributable to computerized tomography examinations in adult patients, although several investigations are currently under way in an effort to further elucidate the radiation-related risks of this imaging modality in adults[1].

There are a number of limitations to the current investigation. The imaging parameters and protocols may vary among different institutions, which might conceivably affect radiation exposure and the subsequent calculations of the effective dose. By necessity, this analysis also entails certain assumptions about the relative radiosensitivities and exposures of various tissues. This retrospective study calculated the effective doses of radiation and did not directly measure radiation exposure from computerized tomographic examinations. Nevertheless, we believe that these extrapolations are based on the best data available, and they were performed with use of validated methodology.

In conclusion, we believe that this is the first study to elucidate the overall radiation exposure inherent to computerized tomographic examinations of the musculoskeletal system. While the effective dose of computerized tomographic scans involving the distal aspect of the extremities is largely trivial, computerized tomographic imaging of the spine or other anatomic structures in close proximity to the axial skeleton such as the shoulders, hips, or pelvis may subject the patient to significantly greater quantities of ionizing radiation. Although we know of no report that has definitively established an increased prevalence of malignant disease secondary to diagnostic imaging procedures, our findings suggest that computerized tomographic examinations are not benign and we believe that recognition of these theoretical risks must play a role in the clinical decision-making process of any physician who regularly acquires these scans for the purpose of evaluating musculoskeletal conditions. ■

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