The rapid developments in computed tomography (CT) technology over the last decade and its expanding clinical applications have markedly increased the number of CT examinations performed and the average scanned volume obtained per examination. In the last decade, CT accounted for 5% of radiologic examinations globally, and about one third of the overall medical ionizing radiation exposure (1). The use of CT is steadily increasing, and CT scanning accounts for about 15% of procedures and 75% of the diagnostic radiation dose received by patients in large hospitals (2). Because the CT technique is extensively used in benign diseases as well as in young patients, it is of paramount importance for public health to use the lowest acceptable dose during routine diagnostic imaging. However, contrary to other X-ray based examinations, scanning parameters in CT studies are not uniform for most patients, and large variations in CT practice exist (3, 4). Previous surveys of CT practice and dose show that effective dose for a given CT study may vary by a factor of 40 between departments (5). In the face of rising demand for CT examinations, radiologists should optimize the scan parameters to ensure that the patient dose is kept to a minimum. To reduce the radiation dose, appropriate strategies have been developed to optimize scanning practices based on clinical indications, the age or body size of the patients, and the area being investigated (6). The purpose of this study was to investigate the practices and policies of the radiology departments of the academic institutions regarding the application of low dose CT in routine daily practice.

**Materials and methods**

In August 2004, we electronically mailed a questionnaire regarding the use of low dose CT in daily practice to 40 radiology departments in Turkey. Emphasis was made to ensure that the questionnaire form be filled by faculty radiologists working directly with CT. Respondents were asked to complete the survey and return it by e-mail, fax, or by regular mail to the authors. The survey was electronically mailed several times more through September-December 2004 to remind and enhance the response rate. Only one response was allowed from each institution. The specific survey questions are shown in Figure. The first two questions asked the type and total number of CT scanners at the respondent’s institutions, and the total number of CT examinations performed within the last year. The third question asked whether the respondent’s department optimizes the CT scanning parameters in order to reduce the patient dose. Those who answered “no” to this question were directed to the final portion of the survey, which asked the respondents to provide the specific area they are working in radiology and the statement of the name of their hospital or institution. For those respondents who answered “yes” to the third question, subsequent questions gathered information about how
Questionnaire: Practices and Strategies for Low Dose CT
(To be completed by faculty radiologists directly working with CT)

1. Please select the type and indicate the number of CT scanners at your institution. Please check all that apply.
   - Single slice axial CT
   - Spiral (helical) CT
   - Multislice CT
   - Electron beam CT

2. How many CT examinations were performed at your institution in the past year?

3. Do you modify the scanning parameters in order to reduce the patient dose?
   - Yes [__Always ___ Often ___ Sometimes ___ Seldom]
   - No (Please skip questions 4-6, and go to question 7.)

4. In which of the following patient populations do you adjust the scanning parameters? Please check all that apply.
   - Pediatric patients
   - Pregnant patients
   - Slim patients (dose adjustment according to weight)
   - Other, please list

5. In which of the following CT examinations do you optimize the scanning parameters? Please check all that apply.
   - Paranasal sinus CT
   - Chest CT
   - Chest HRCT
   - Abdominal CT
   - CT for urinary tract calculi
   - CT colonography
   - CT-guided interventional procedures
   - Other, please list

6. Which of the following modifications do you use for reducing patient dose? Please check all that apply.
   - Reduced mAs
   - Reduced kVp
   - Increased pitch
   - Reduced area of image acquisition in the z-axis
   - Thicker collimation (wider beam collimation)
   - Single-detector helical CT scanner rather than multislice
   - Automatic modulation of tube current (if present)
   - Shielding of radiosensitive organs
   - Avoiding multiphasic CT of the abdomen if not indicated
   - Other, please list

7. Please identify the area (based on the system or modality) you are involved in radiology

8. Please indicate the name of your hospital or academic institution

Figure. Questionnaire used in the study.

Results
Out of 40 individuals representing 40 institutions, 33 completed and returned surveys representing an 82% response rate on an institutional basis. There were overall 61 CT scanners in 33 institutions representing the 8.5% of overall 715 CT equipment in Turkey; 14 institutions had one scanner, 13 had two, 3 had three, and 3 had four scanners. The annual number of CT examinations performed in these institutions ranged between 3,000 and 44,369 (mean±standard deviation, 13,988±9,075) resulting in 4,910 examinations per CT scanner. Concerning the type of CT equipment, 13 (39%) of 33 respondents reported to have only single-slice helical CT, 3 (9%) have only multislice CT, and 2 (6%) have only conventional non-helical (axial) CT. Both single-slice helical CT and conventional non-helical CT were present at 7 (21%) institutions, both single-slice helical CT and multislice CT were available at 6 (18%) institutions, and conventional non-helical CT, single-slice helical CT and multislice CT scanners were present at two (6%) departments.

Of the 33 respondents, 28 (85%) reported that they modified CT scanning parameters in order to limit the radiation exposure to patients. Regarding the frequency with which low dose CT modifications are performed, five (18%) of 28 respondents reported that they always optimized the parameters, 10 (36%) often, 11 (39%) sometimes, and 2 (7%) seldom. Concerning specific patient groups, children were the population in whom reduced dose CT was performed most frequently by 26 (93%) of 28 respondents. Sixteen (57%) respondents reported that they modified CT parameters in pregnant patients, and 3 (9%) reported that they did not work with pregnant patients. Low dose CT adjustments for slim patients were reported by 11 (39%) respondents. Chest was the most common body part for the application of low dose CT reported by 19 (68%) of 28 respondents, followed by the paranasal sinuses (n=15, 54%), and abdomen (n=14, 50%). Less than 50% of the respondents reported to perform low dose CT for CT-guided interventions, CT for urolithiasis, high resolution CT of the chest, and CT colonoscopy (Table).

often and in what kind of patients or CT examinations they perform low dose CT, and the use of dose-reduction strategies. Finally, the respondents were asked to identify the specific area they are working in radiology and the name of their hospital or institution. The total number of licensed CT scanners in Turkey was obtained from the Turkish Atomic Energy Agency.
Regarding dose reduction, low mA was the most common technique used by 26 (93%) of the 28 respondents followed by high pitch (n=12, 43%) and low peak kilovoltage (n=11, 39%). Other modifications including shielding of radiosensitive organs, avoiding multiphasic examination in the abdomen if not necessary, using automatic modulation of tube current, using thicker collimation, reducing the area of z-axis coverage were reported by less than 25% of the respondents (Table). Of the nine respondents who had both single-slice helical and multislice CT, only one (11%) chose to use a single-slice helical CT scanner rather than a multislice scanner to limit dose. Three (11%) respondents reported they only applied one modification (reduced mA, n=2; reduced kVp, n=1), 12 (43%) respondents reported they modified two parameters (reduced mA and reduced kVp, n=3; reduced mA and increased pitch, n=3; reduced mA and automatic modulation of tube current, n=2; reduced mA and shielding, n=2; reduced mA and avoiding multiphasic study, n=2). The adjustment of three parameters was reported to be applied by eight respondents (29%), four parameters by three (11%), five parameters by one (3%), and six parameters by one (3%) respondent.

Concerning the radiologic practices of the 33 respondents who completed the survey, 8 (24%) were chest radiologists, 7 (21%) were abdominal radiologists, and 4 (12%) were head and neck radiologists. Four (12%) respondents worked as chest and abdominal radiologists, four (12%) worked as chest, abdominal, pediatric, and head and neck radiologists, two (6%) worked as chest and head and neck radiologists, two (6%) worked as chest, abdominal, and head and neck radiologists, one (3%) worked as a chest, abdominal, and pediatric radiologist, and another one (3%) worked as a pediatric and abdominal radiologist.

### Discussion

The United Nations Scientific Committee on the Effects of Atomic Radiation 1993 Report stated that about 93 million CT examinations were performed worldwide on an annual basis, corresponding to a frequency of 16 examinations per 1,000 inhabitants (7). Introduction of helical and multislice CT significantly increased the use of CT, particularly in vascular, cardiac, and oncologic imaging, that is likely to increase radiation dose further (4, 6). The ionizing radiation associated with CT examination may induce carcinogenesis in the subjects and genetic effects in the offspring of the irradiated individuals due to stochastic effects. According to the recommendation of International Commission on Radiological Protection (ICRP), the risk of cancer induction from CT can be estimated by using the population average risk of 50 induced cancers per mSv of effective dose per million people exposed (8). Therefore, the radiologists must be attentive to their responsibility to maintain an appropriate balance between diagnostic image quality and radiation dose. CT scan parameters should be optimized to keep the radiation exposure as low as reasonably achievable to obtain diagnostic-quality examinations. Several strategies can be applied to reduce the CT radiation dose without significant deterioration in image quality (6). In this survey, we investigated the practices and policies of the radiology departments of the academic institutions in Turkey regarding the use of low dose CT in routine daily practice. Our 82% response rate is higher than the response rates for other surveys that have been published in the radiology literature inquiring practice patterns of radiologists (9, 10).

The mean total number of annual CT examinations performed with 61 scanners in thirty-three institutions was 14,000 (i.e., 4,910 examinations per CT scanner). Multiplying this number with 715 licensed CT equipment, we can roughly estimate that over 3.5 million CT examinations are performed in Turkey on an annual basis, corresponding to a 5% of the population. This rate is in accordance with the frequency of CT examinations in Western world.

Our results show that the majority (85%) of respondents adjust CT parameters to reduce the radiation dose, but only 18% optimize factors in every patient. On the other hand, nearly half (46%) of the respondents using low dose CT manipulate the parameters sometimes or rarely. This result indicates that most of the respondents have concerns about CT radiation dose, but they seldom employ specific low dose CT protocols for routine use.

### Table. Practices and strategies of the radiology departments regarding the optimization of radiation dose for CT

<table>
<thead>
<tr>
<th>Frequency of adjustments of scan parameters for LDCT (n=33)</th>
<th>Adjustments of scan parameters for specific patients (n=28)</th>
<th>Adjustments of scan parameters for body parts being examined (n=28)</th>
<th>Modified scan parameters for LDCT (n=28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always</td>
<td>Children</td>
<td>Chest CT</td>
<td>Reduced mA</td>
</tr>
<tr>
<td>5 (15%)</td>
<td>26 (93%)</td>
<td>19 (68%)</td>
<td>26 (93%)</td>
</tr>
<tr>
<td>Often</td>
<td>Pregnant patients</td>
<td>Paranasal sinus CT</td>
<td>Increased pitch</td>
</tr>
<tr>
<td>10 (30%)</td>
<td>16 (57%)</td>
<td>15 (54%)</td>
<td>12 (43%)</td>
</tr>
<tr>
<td>Sometimes</td>
<td>Slim patients</td>
<td>Abdominal CT</td>
<td>Reduced kVp</td>
</tr>
<tr>
<td>11 (34%)</td>
<td>11 (39%)</td>
<td>14 (50%)</td>
<td>11 (39%)</td>
</tr>
<tr>
<td>Seldom</td>
<td>CT-guided interventions</td>
<td>CT for urolithiasis</td>
<td>Avoiding multiphasic exam</td>
</tr>
<tr>
<td>2 (6%)</td>
<td></td>
<td>10 (36%)</td>
<td>7 (25%)</td>
</tr>
<tr>
<td>Never</td>
<td>High resolution chest CT</td>
<td>CT colonoscopy</td>
<td>Shielding</td>
</tr>
<tr>
<td>5 (15%)</td>
<td>9 (32%)</td>
<td>4 (14%)</td>
<td>6 (21%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CT for abdominal CT</td>
<td>Automatic modulation of tube current</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5 (18%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CT colonoscopy</td>
<td>Reduced scan length</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 (14%)</td>
</tr>
</tbody>
</table>

LDCT: Low dose CT
respondents performed chest CT, and dents, respectively, in children 4 years men by 33% and 22% of the respon-
s should be knowledgeable about ra-
safe for fetal exposure, radiologists
protocols to reduce the dose (9). Al-
pregnant patients modify their CT
work with pregnant patients because
improved an abdominal CT angiography
imaging during all trimesters (17). In a recent survey investigating the
among Society of Thoracic Radiology members regarding the
niary obesity is associated with a lower average fetal radiation
tube current of less than 100 mA was used for helical CT of the chest and abdo-
by 33% and 22% of the respond-
children 4 years old and younger. However, 14% of the
CT with tube currents equal to or greater than
With regard to pregnant patients, 57% of respondents in our survey reported that they optimize CT param-
tube currents equal to or greater than

Patient-based strategies

Most radiologists in this survey were aware of the radiosensitivity of chil-
dren, and 93% of respondents report-
edly apply reduced dose CT in pediatric population. It has been shown that children, particularly girls, are 10 times more sensitive than adults to the risk of cancer induction from the same effective dose of ionizing radiation, and the effective dose is up to 50% greater when the radiation doses in adult proto-
colos are used in neonates or young children (11-13). Furthermore, previ-
ous studies have documented that CT images of acceptable quality can be
obtained with 50% less radiation (14-18). However, in a survey among the
members of Society for Pediatric Radiology, 15%-40% of respondents were
found to be unaware of the techniques used at their institutions, particularly
those parameters determining radiati-
on exposure (19). In that survey, a
tube current of less than 100 mA was used for helical CT of the chest and abdo-
men by 33% and 22% of the respondents, respectively, in children 4 years old and younger. However, 14% of the
respondents performed chest CT, and
16% performed abdominal CT with
tube currents equal to or greater than
200 mA.

With regard to pregnant patients, 57% of respondents in our survey reported that they optimize CT param-
ters, and 9% reported that they do not work with pregnant patients because
of concerns about either radiation dose or use of i. v. contrast material. Win-
er-Muram et al. have reported that CT angiography for pulmonary embolism is
associated with a lower average fetal radiation dose than ventilation–per-
fusion imaging during all trimesters (17). In a recent survey investigating the
strategies among Society of Tho-
racic Radiology members regarding the use of CT pulmonary angiography
in pregnant patients, Schuster et al. reported that only 40% of 43 respond-
ents who perform CT angiography in pregnant patients modify their CT
protocols to reduce the dose (9). Al-
though the fetal radiation exposure
during CT scan in pregnant patients is
well below the 5-rad limit considered
safe for fetal exposure, radiologists
should be knowledgeable about ra-
diation risks and exposures associated
with CT imaging, and weigh up the
risks and benefits before proceeding to

In contrast to large patients in whom the
CT scan. Alternative imaging modali-
ties such as sonography or magnetic
resonance imaging should be consid-
ered when appropriate.

Body part-based strategies

The body part being examined is also
important in the optimization of CT
scanning parameters. CT radiation dose
can be substantially reduced particular-
ly in those structures with a high in-
herent contrast, such as CT of the chest
and paranasal sinuses, CT colonogra-
phy and CT for urolithiasis. Previous
studies have shown that it is possible
to reduce CT dose two to ten-fold (140-
10 mAs) in chest (21-25) and paranasal
sinus imaging (26-29), CT colonogra-
phy (30), and CT for urinary tract calculi
(31-33) without severely compromis-
ing the image quality necessary to
maintain a diagnostic standard. In our
survey, chest was the most common
body part in which low dose CT was
applied, reported by 68% of respond-
ents, followed by CT of the paranasal
sinuses (54%), abdominal CT (50%),
CT-guided interventions (43%), CT for
urolithiasis (36%), high resolution CT
of the chest (32%), and CT colonosco-
py (14%). These rates show that nearly
half of the respondents did not reduce

Adjustment of scan parameters

The radiation dose delivered during
CT scanning is related to tube current,
voltage, scanning time, slice thickness,
scanning volume, and pitch. Previous
studies have suggested that it is feasible
to reduce tube current without marked
deterioration of image quality in CT of
the head and neck, chest, abdomen, and pelvis (21-33). Our survey showed
that reduced tube current is the most
common modification reported by 93%
followed by increased pitch (43%) and
reduced peak kilovoltage (39%). Tube
potential determines the X-ray beam
energy, and radiation dose is propor-
tional to the square of the tube voltage.
In a recent study, it was shown that 80
kV was an acceptable setting for chest
CT in adults weighing less than 75 kg,
without substantial impairment in im-
age quality (34). Using a 16 detector-row
CT scanner, Wintersperger et al. imple-
mented an abdominal CT angiography
protocol using 100 kVp and concluded
that tube voltage reduction from 120
to 100 kVp allows for significant re-
duction of patient dose in abdominal
CT angiography, without significant
change in signal to noise and contrast
to noise ratios and image quality (35).
However, any decrease in tube cur-
rent and voltage should be considered
carefully, because they increase image
noise, which may hamper diagnostic
outcome of the information, particu-
larly in low contrast areas, such as ab-
domen or brain. Pitch is defined as the
ratio of table feed per 360° gantry rota-
tion to the nominal x-ray beam width.
An increase in the pitch decreases the
duration of radiation exposure to the
scan volume. However, effective milli-
lampere second is held constant
regardless of pitch in scanners using
effective milliamperage second setting,
defined as milliampere second divided
by the pitch (36). No significant differ-

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ere was demonstrated in image quality of scans obtained at a pitch of 1:5:1 compared to those obtained at a pitch of 0.75:1 saving 50% radiation dose in abdominal and pelvic imaging (37).

In a recent survey investigating the methods of dose reduction in pregnant patients suspected for pulmonary embolism, the most common modification was to decrease the scanning area along the z-axis, reported by 71% of respondents (9). In our survey only 14% of respondents indicated that they decrease the scanning length. Radiologists in our study group may be inclined to increase the area of coverage beyond the actual area of interest at the expense of higher effective radiation dose.

The availability of multislice CT scanners has resulted in a considerable increase in the number of CT procedures per patient and per scanner. A recent survey revealed that the mean effective dose to patients has increased from 7.4 mSv at single slice helical CT to 8.1 mSv at quad-slice CT system (38). Recent commercially available multislice CT scanners have automatic tube current modulation capability; that is the most important contribution of industry toward radiation dose optimization while simultaneously maintaining constant image quality regardless of patient attenuation characteristics. The two methods of this technique are z-axis modulation and angular (x-y axes) modulation. In 100 helical CT examinations in children, angular modulation was reported to decrease dose 10%-60% without loss of image quality (39). A recent investigation of 22 patients with kidney and ureteral stones in whom z-axis modulation was used showed a 43%-66% reduction in radiation dose at noise indexes of 14 and 20 without compromising stone depiction (40). In this survey, five (45%) of 11 respondents, who have multislice CT scanners, reported to use automatic tube current modulation technique. Our survey has several limitations. First, because it is limited to radiologists who practice in an academic setting, our results are indicative of the current state of low dose CT strategies in academic environments. As academic radiologists are more likely to be aware of the low dose CT strategies, policies may differ significantly among radiologists in public hospitals or private practice. A second limitation of our study is that because only one response was allowed from each institution, it does not reflect the strategy of an entire department, because interindividual variations in the practice patterns could occur in the same institution. A third limitation is that our survey asked general questions with respect to dose reduction to a relatively heterogeneous group of academic radiologists working with different types of CT scanners. Specific questions directed to particular subspecialty radiologists regarding specific clinical indications would have more appropriately reflected the tendency of using low dose CT strategies. A fourth limitation is that, with regard to the frequency of low dose CT modifications, the choices given to respondents were not precise numbers, but rather arbitrary adverbs. Thus, excluding the respondents stating that they “always” optimize the scan parameters, other frequencies designated by “seldom”, “sometimes”, and “often” could have been overlapped. Similarly, in the question 6, we did not ask the absolute numbers for reducing the mA, kVp and increasing the pitch. Therefore, our rates for the application of low dose strategies might have been erroneously affected. For example, reducing mA from 400 to 300 may appear as low dose application, but indeed it is not at all.

In conclusion, our survey reveals that most radiologists are aware of the radiation dose the patient exposed during CT scan. However, the frequency of use of low dose CT strategies varies vastly, mostly due to the lack of well-established CT protocols designed for either specific indications or particular patients. In compliance with the rules of “as low as reasonably achievable”, the radiologists should prepare practice CT dose optimization guidelines for routine practice depending on the body part being examined and indication for the study, or on the basis of patient’s age and size.

References


