Technical notes

Radiation dose in repeated CT guided radiofrequency ablations

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ARTICLE INFO

Article history:

Received 19 February 2013

Received in revised form

1 April 2013

Accepted 19 April 2013

Available online 13 May 2013

Keywords:

CT-guided radiofrequency ablation

Patient dose

Effective dose

Skin dose

ABSTRACT

Objective: To calculate the cumulative effective and skin doses in patients that underwent repeated CT guided radiofrequency ablations (RFA).**Materials and methods:** From all patients that had undergone RFA during a five years period those which had three or more RFAs were selected. Using the CT images DICOM data, the dose length product (DLP), effective dose (*E*), skin dose profiles as well as the peak skin dose (PSD) were calculated, using appropriate methods and software developed for this purpose. For each patient, cumulative DLP and *E* were also calculated from the sum of the respective figures of each individual procedure. To calculate PSD, the skin dose profiles of each procedure were overlaid on the same Z-axis scale using anatomical landmarks for reference and the skin doses to each point were summed up.**Results:** Five patients were studied; four had undergone 3 RFAs and one 10 RFAs. Cumulative DLP, *E* and PSD ranges were 5.6–22.3 Gy cm, 0.08–0.36 Sv and 0.8–3.4 Gy, respectively. Median *E* and PSD values per RFA were 35 mSv and 0.4 Gy, respectively. For comparison purposes it must be noted that in this CT department a routine abdomen-pelvis scan results to an *E* of about 10 mSv.**Conclusions:** Patients that undergo repeated RFAs are exposed to considerably high radiation exposure levels. When these patients are in the final stage of malignant diseases, stochastic effects may not be of major concern. However, optimization of the exposure factors and monitoring of these patients to avoid skin injuries are required.

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Introduction

The vast technological advances have enabled various ways for the treatment of malignant tumors. During the last years, radiofrequency ablation (RFA) has received large attention as a minimally invasive strategy for the treatment of focal malignant disease [1]. It has been successfully used for the treatment of primary solid tumors of the liver, renal neoplasms, as well as, colorectal metastases [2]. Although other therapeutic methods also exist (cryotherapy or ethanol injection), their complication rates are moderately high whereas their efficacy is considered suboptimal [1]. On the contrary, complication rates using RFA are reasonably low and reduced mortality, morbidity and hospitalization are the main advantages of this technique [3]. Furthermore, the use of RFA has increased the number of candidates for surgery, since its combination with hepatic resection of tumors provides therapeutic possibilities that would seem impossible in earlier days.

RFA can be performed using a percutaneous electrode insertion under image guidance [4,5]. Computed tomography (CT) is one of the imaging techniques currently used for performing RFA (ultrasound and magnetic resonance imaging are also used). The main advantages of CT guided RFA are: a) it can be repeated many times if required, with much lower cost compared to magnetic resonance imaging, and b) it provides a more detailed imaging of the morphological characteristics of the lesion to be treated compared with ultrasound, which allows more accurate localization [6]. The main disadvantages of CT guided RFA is the use of ionizing radiation [6]. Therefore, the radiological burden needs to be estimated, since the patient is exposed to a certain risk from the stochastic (mainly cancer induction) and the deterministic effects of radiation (like skin injuries) [7].

For stochastic effects it is generally believed that no threshold exists and the probability of occurrence increases roughly linearly with patient dose. To quantify the stochastic risk effective dose (*E*) is considered as the most suitable dosimetric quantity. Deterministic effects are immediate effects that have a threshold below which no direct radiation induced damage occurs to tissues and organs. The deterministic effects to the skin require a peak skin

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dose (PSD) of at least 2 Gy to occur, however, doses of this magnitude are not considered uncommon for some CT guided procedures [8,9]. Skin doses up to about 1 Gy have been reported for CT guided RF ablation, most of which are due to the scans acquired during the positioning of the needle [9].

Having in mind that: a) patients can be treated more than once with CT guided RFA [6,10,11] and b) the possibility of deterministic effects cannot be excluded if several radiological procedures are performed on the same patient over the same anatomical region in a short time period [12], patient radiation doses need to be evaluated. International literature contains very limited data regarding patient dose during CT guided interventional procedures [8,9,13–15] and no dose information on multiple CT guided RFA techniques. Taking all these factors into consideration, we evaluated patient doses in patients who undergone more than three CT guided RFA procedures.

Materials and methods

The retrospective review included patients who underwent three or more RFA procedures during a five years study period in the CT department of Konstantopoulou General Hospital of Athens. In this CT department, a wide range of CT guided interventions are performed such as RFAs, biopsies, abscess drainages and nephrostomies. The CT scanner used for these techniques was a single-slice helical CT scanner without CT fluoroscopy capability (Prospeed SX Power, General Electric Medical Systems, Milwaukee; WI, USA).

This CT scanner is rather old and does not have software to calculate the volume weighted computed tomography dose index ($CTDI_{vol}$) and the dose length product (DLP), which are readily available in modern CT scanners. However, since all CT procedures were routinely transferred and stored in the CT department's PACS using the DICOM protocol, the technical parameters used for the acquisition of each image (e.g. tube potential, tube current, scan time, collimation etc.) could be retrieved to enable the retrospective calculation of $CTDI_{vol}$ and DLP. The methods and software used to calculate $CTDI_{vol}$, DLP, E , entrance skin dose (ESD) profile and PSD values from DICOM data are described in detail elsewhere [13,9]. In brief, these methods are based on the ImPACT CT Patient Dosimetry Calculator (CTDosimetry.xls), a Microsoft Excel based program freely available in the Internet (<http://impactscan.org>). With CTDosimetry the DLP of a scan can be calculated provided that the technical parameters (tube potential, tube loading, collimation, pitch, scan start and scan end table positions) are known. When the anatomic area scanned is defined on the mathematic phantom included in CTDosimetry for simulating human anatomy and the National Radiological Protection Board (NRPB) SR250 data sets (containing conversion coefficients derived from Monte Carlo simulations) [16] are available, an estimate of E can also be obtained along with the DLP. For routine CT examinations comprised usually by one, two or three scans series this is a rather simple procedure. However, for complex interventional procedures, like RFAs, which involve the acquisition of multiple scans at various locations, a Microsoft Excel based program with embedded functions was devised, that had the capacity of exchanging data with CTDosimetry in order to calculate cumulative DLP and E from multiple acquisitions and furthermore provide a crude estimate of the ESD profile and the PSD [13]. In the revised version of that program [9], the ESD profiles and PSD values were calculated considering that each slice results to a Gaussian shaped dose profile, whose peak dose value and full-width at half maximum (FWHM) are dependent on the distance from the isocenter. For both the patient's bottom and top skin surfaces, the dose profile of each individual slice was separately considered and for

each point in the z-axis the sum of the contributions of all slices were calculated to derive the ESD profiles for the bottom (ESD_B) and top (ESD_T) skin surfaces, as well as, the respective PSD values (PSD_B and PSD_T). It must be noted that due to the effect of the X-ray beam intensity shaping filters (bowtie filter) of CT scanners, the patient's surface that is more exposed is that being closer to the gantry isocenter [9].

From the department's archives it was initially found that during the study period 15 patients had undergone three or more RFAs. Seven of these patients were treated 3 times, six were treated 4 times, one was treated 6 times and one 10 times. Six of the patients suffered from colorectal cancer with liver metastases, five from hepatoma and the rest of the patients had various solid tumors such as small intestine carcinoid tumor, lung carcinoma, gall-bladder carcinoma and adrenal sarcoma with liver metastases. Procedure-related complications or treatment related deaths had not been reported during the study period. From the initial patient sample, five patients (mean age 68 ± 10 years) with liver masses were selected for further analysis (four patients with three and one patient with 10 RFAs) for which all RFAs procedures were still stored in the CT department's PACS. For the rest patients DICOM data of one or more RFA procedures have been lost.

For each one of the 22 RFAs studied, the DLP, E , ESD_B and ESD_T profiles, and additionally, PSD_B and PSD_T values were calculated. Furthermore, for each patient cumulative DLP and E values were calculated as the sum of the respective values of individual RFA procedures. The cumulative ESD_B and ESD_T profiles, for each patient were calculated by overlaying the respective profiles of each individual procedure on the same Z-axis scale (using anatomical points for reference) and summing up their contribution at each Z-axis point. From these cumulative profiles ESD_B and ESD_T profiles, the PSD_B and PSD_T values were calculated.

Results

Table 1 present the radiation doses in terms of DLP, E , PSD_B and PSD_T for the 22 RFAs performed in 5 patients (the age of each patient is also given). The youngest patient (53 years) was the one who underwent the largest number of RFA techniques, having 2 lesions treated, and also was the one with the largest cumulative DLP and E values. However, the largest PSD_T was observed in patient 1 who had only 3 RFAs. As seen in Table 1, the values of DLP, E , PSD_B and PSD_T varied greatly even for the same patient as a result of the number of lesions, lesion location, and accessibility. Furthermore, the respective cumulative values also varied, depending not only on the number of RFAs performed but also on the difficulty of the individual RFAs performed in each patient.

A statistical overview of the DLP, E , PSD_B and PSD_T values per procedure is given in Table 2, in terms of minimum, maximum, median and average values. The median E value per RFA was 35 mSv which is quite high compared to the value of about 10 mSv resulting from a routine abdomen-pelvis scan in this CT scanner. The median PSD_T was 400 mGy whereas the skin dose throughout the patient irradiated skin area in a routine abdomen-pelvis examination is about 25 mGy (assuming acquisition with 120 kV, 200 mAs).

Figure 1 shows the graphical representation of skin dose distribution in patient 1, separately for each individual RFA (black line curves) and the cumulative ESD_T profile (white line curve) overlaid on the scanogram. As the figure shows, the patient had one anatomical location treated at which the cumulative PSD_T reached 3.4 Gy.

Figure 2 shows the distributions of ESD_T in patient 5 who had 10 RFA in total, separately for each RFA (black line curves) and the cumulative ESD_T profile (white line curve) overlaid on the scanogram. As understood by the cumulative ESD_T profile, the patient

Table 1

Radiation doses in terms of dose length (DLP), effective dose (E) and peak skin doses in the bottom and top patient surfaces (PSD_T and PSD_B , respectively) are shown for all RFAs studied. For each patient the cumulative values from all RFAs are also shown in bold. It should be clarified that unlike the cumulative values of DLP and E which are simple sums, cumulative PSD_B and PSD_T values resulted from summing up the respective profiles and not the PSD_B and PSD_T values of individual RFAs.

N	DLP (Gycm)	E (mSv)	PSD_B (Gy)	PSD_T (Gy)
Patient 1 (75 years)				
1	2.21	39	0.55	0.85
2	3.76	64	0.98	1.40
3	3.68	70	1.10	1.55
Cumulative	9.64	173	2.29	3.36
Patient 2 (77 years)				
1	2.76	50	0.81	0.70
2	1.95	36	0.37	0.45
3	1.69	28	0.31	0.58
Cumulative	6.41	114	1.07	1.27
Patient 3 (76 years)				
1	1.83	31	0.28	0.40
2	1.58	27	0.22	0.29
3	2.27	35	0.29	0.40
Cumulative	5.68	93	0.77	1.07
Patient 4 (59 years)				
1	2.74	34	0.99	0.99
2	1.15	15	0.42	0.42
3	1.68	33	0.52	0.52
Cumulative	5.57	82	1.36	1.51
Patient 5 (53 years)				
1	1.51	26	0.24	0.28
2	2.63	44	0.29	0.42
3	2.46	42	0.29	0.39
4	1.95	33	0.36	0.29
5	2.40	40	0.29	0.25
6	2.20	33	0.21	0.24
7	2.63	44	0.13	0.09
8	2.36	35	0.23	0.22
9	2.20	36	0.25	0.22
10	1.94	29	0.21	0.16
Cumulative	22.27	362	1.65	1.67

had two anatomical locations treated. The cumulative ESD_T reached 0.9 Gy in the one anatomical site treated and 1.7 Gy in the other.

Discussion

As seen in Table 1, the peak skin doses did not exceed the threshold of 2 Gy in none of the individual RFAs studied, however, in two RFAs performed in patient 1 exceeded 1 Gy and in one more RFA procedure (patient 4, 1st RFA), it was very close to 1 Gy (0.99 Gy). The cumulative peak skin dose exceeded 1 Gy in all five patients studied but in only one patient exceeded the threshold of 2 Gy. According to ICRP Publication 85 [7], when the maximum cumulative absorbed dose in skin for an actual procedure appears to approach, equal or exceed 1 Gy for procedures that may be repeated and 3 Gy for any individual procedure, it should be recorded in the patient record, along with the location and extent of the skin site. Given the variable time interval between successive procedures it is difficult to state with certainty if any actual radiation damage may result in the skin as a result of peak skin doses

Table 2

Analysis of the 22 RFAs studied in terms of minimum, maximum, median and average DLP, E , PSD_T and PSD_B values.

	DLP (Gycm)	E (mSv)	PSD_B (Gy)	PSD_T (Gy)
Min	1.15	15.0	0.13	0.09
Max	3.76	70.0	1.10	1.55
Median	2.21	35.0	0.29	0.40
Mean	2.25	37.5	0.42	0.51

Figure 1. The figure shows the distributions of ESD_T in patient 1, separately for each RFA (black line profiles) and cumulative ESD_T (white line profile). As the figure shows, the patient had only one anatomical location treated, at which the cumulative PSD reached 3.4 Gy. (The dotted numbered lines denote the position of each reconstructed image on the scanogram and they were used for corresponding of the ESD profiles on the scanned anatomy).

which in individual RFAs are below the threshold of 2 Gy (for transient erythema) but when “summed-up” are above it.

The results of this preliminary study indicate that radiation doses in terms of E and PSD are rather high and therefore there is a relatively high risk for the induction of a radiogenic cancer. Furthermore, there is a small possibility for the occurrence of radiation injuries, if repeated high skin dose procedures are performed over a short time scale, and for this reason monitoring of the patients where high PSD values are observed is needed.

Given the fact that these repeated procedures are usually carried out in patients where malignant tumors are already present and their medical condition is life threatening, the stochastic effect risk can be considered of secondary priority. Furthermore, though the youngest patient in this study was 53 years old and was the one with the highest cumulative effective dose, it is not common to

Figure 2. The figure shows the distributions of ESD_T in patient 5, separately for each RFA (black line profiles) and the cumulative ESD_T (white line profile). From the cumulative skin dose profile it can be understood that the patient had two anatomical locations treated. In one location the cumulative PSD reached 0.9 Gy and in the other 1.7 Gy.

have young patients undergoing multiple RFA procedures. Taking into account that radiation induced cancer requires a certain number of years to appear, it is apparent that cancer radiation risk is not a major problem under such circumstances. On the other hand, one must take this into account when considering CT guided RFA treatment in young patients.

It should be noted, however, that despite the fact that the patient cumulative doses in repeated RFAs may become very high, still these procedures cannot be ruled out on the grounds of radiation risk. The reasons are the prolongation of life expectancy and the improvement of the quality of life that these procedures offer which certainly justify these risks. CT imaging defines more accurately the expected area of ablation based on the shape of the tumor compared with conventional ultrasonography. Moreover, repeated treatment is efficiently performed with CT due to better differentiation of viable from ablated tumor compared with ultrasonography. On the other hand, optimization of the technical factors and monitoring of skin radiation dose are both required in order to avoid the incidence of skin radiation injuries. These injuries may give rise to complications which could possibly aggravate the subtle health condition of these patients, thus canceling out, in part, the benefits of these procedures.

The main limitation of this study is the small number of patients due to the fact that such medical cases are not common. Due to the high effective and skin doses observed, it was decided to continue the study so as to further investigate multiple RFA procedures in a larger patient sample.

Conclusion

While surgical resection remains the gold standard for treating various primary and secondary liver lesions, only a few patients are suitable candidates for curative surgical resection, for various reasons. Percutaneous RFA is well documented to be the best alternative and it seems to be safe and efficient. The use of CT to perform the RFA has many advantages such as: large availability of CT scanners, confirmation of probe placement in relation to the tumor site, as well as precise visualization of the extent of ablation. An important disadvantage of CT when used in multiple RFA procedures is the large amount of radiation doses to patients. Taking into consideration that multiple RFA are performed in patients that are in a more advanced stage and/or cannot undergo surgical resection, it is concluded that optimization of the technical factors, monitoring of skin radiation dose and patient follow-up for

radiation skin injuries, are required in order to reduce as possible the radiation risk.

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