View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by shahrekord university of medical scinces

Comparison of Intratumor and Intraluminal Temperatures During Locoregional Deep Hyperthermia of Pelvic Tumors

Daryoush Fatehi[1,2], Jacoba van der Zee[1], Annelise Notenboom[3], Gerard C. van Rhoon[1]

Purpose: To investigate whether intraluminal thermometry provides sufficient information to apply high quality deep hyperthermia in pelvic tumors.
Patients and Methods: The intratumor and intraluminal temperatures of 48 patients were analyzed per cancer type: rectum (21 male, 14 female), cervix (n = 8), and bladder (n = 5). Temperature-dose parameters were calculated, temperature curves within each treatment session were compared, and correlation between intratumor and intraluminal temperatures was analyzed.
Results: Intratumor and intraluminal temperatures at the same time points during individual treatments were highly correlated (mean correlation coefficient: 0.93). However, the quantitative level differed from 0.1 to 1.1 °C and the differences of the time-temperature graphs varied per tumor group. Average intratumor and intraluminal temperatures were not different in the four groups. Intratumor thermometry was found not superior over intraluminal thermometry to improve tumor temperature level and homogeneity by SAR steering.
Conclusion: Intraluminal thermometry provides sufficient information to apply deep hyperthermia to individual patients with centrally located rectum, cervix or bladder cancer.

Key Words: Hyperthermia · Pelvic tumor · Intratumor/intraluminal thermometry

Strahlenther Onkol 2007;183:479–86
DOI 10.1007/s00066-007-1768-0

Vergleich von intratumoralen und intraluminalen Temperaturen während lokoregionaler tiefer Hyperthermie von Beckentumoren

Ziel: Es wurde untersucht, ob die intraluminale Thermometrie genug Informationen für die Anwendung einer qualitativ hochwertigen regionalen Hyperthermie bei Beckentumoren liefert.
Patienten und Methodik: Die intratumoralen und intraluminalen Temperaturen von 48 Patienten wurden nach Krebsart analysiert: Rektum (21 Männer, 14 Frauen), Gebärmutterhals (n = 8) und Blase (n = 5). Temperatur-Dosis-Parameter wurden berechnet, die Temperaturkurven im Rahmen jeder Behandlung wurden verglichen, und die Korrelation zwischen intratumoralen und intraluminalen Temperaturen wurde analysiert.
Ergebnisse: Intratumorale und intraluminale Temperaturen zu denselben Zeitpunkten während individueller Behandlungen zeigten eine hohe Korrelation (mittlerer Korrelationskoeffizient 0,93). Die absoluten Temperaturen differierten jedoch von 0,1 bis 1,1 °C, und die Unterschiede in den Zeit-Temperatur-Diagrammen waren tumorgruppenspezifisch. Die mittleren intratumoralen und intraluminalen Temperaturen waren in den vier Gruppen nicht unterschiedlich. Bezüglich einer Verbesserung der Tumortemperatur und der Homogenität fand sich keine Überlegenheit der intratumoralen Thermometrie gegenüber der intraluminalen Thermometrie.
Schlussfolgerung: Die intraluminale Thermometrie liefert genug Informationen zur Anwendung der regionalen Hyperthermie bei individuellen Patienten mit zentral lokalisierten Rektum-, Gebärmutterhals- oder Blasenkarzinomen.

Schlüsselwörter: Hyperthermie · Rektum · Gebärmutterhals · Blase · Intratumor-/intraluminale Thermometrie

[1] Unit Hyperthermia, Department of Radiation Oncology, Erasmus Medical Center, Daniel den Hoed Cancer Center, Rotterdam, The Netherlands,
[2] Department of Medical Physics, Shahrekord University of Medical Sciences, Shahrekord, Iran,
[3] Department of Statistics, Erasmus Medical Center, Daniel den Hoed Cancer Center, Rotterdam, The Netherlands.

Received: April 30, 2007; accepted: May 18, 2007

Introduction

In the recent decades, multimodality treatment approaches for deep-seated pelvic malignancies including surgery, radiotherapy, chemotherapy, and hyperthermia have become increasingly sophisticated [2, 6, 9, 14]. When patients with deep seated tumors are under treatment, hyperthermia groups apply intratumor and/or intraluminal thermometry for temperature data acquisition. Strong variation exists in the opinions whether intratumor thermometry provides superior information over intraluminal thermometry. Sneed et al. [7] state that intratumor thermometry is critically important, while van der Zee et al. [11] and Wust et al. [16] suggest, if intraluminal thermometry is available, intratumor thermometry is neither an important requirement for prevention of toxicity, nor necessary for SAR (specific absorption rate) steering.

Van der Zee et al. [11] focused on the complications and clinical limitations of intratumor thermometry during deep hyperthermia of pelvic tumors and present a very limited thermal analysis. Wust et al. [16] demonstrated that intraluminal measurements, specifically for cervical and rectal cancers, are suitable for estimating feasibility and effectiveness, and that there is no need for intratumor thermometry.

The present study is an extension of that by van der Zee et al. [11]. It provides a rigorous analysis of temperature data, acquired both intratumorally and intraluminally, of patients with pelvic tumors, making it an independent replicate of the study by Wust et al. [16]. Questions were: (1) Is there a positive correlation between intratumor and intraluminal temperatures? (2) What are the quantitative/qualitative differences between intratumor and intraluminal temperatures? (3) Can intratumor temperature distribution be improved by SAR steering?

Patients and Methods

Patients

Data used in this retrospective study were selected from our patients' database. Selection criteria were: (1) intratumor and intraluminal temperature measurements, (2) tumor location: pelvis, (3) tumor type: rectum, cervix, or bladder. Based on these criteria, 58 patients (143 treatments) were selected.

Accessibility of temperature data, as registered by the BSD-2000 system, requires specific tools and it is subjected to failures as explained by Fatehi et al. [3]. For the present study, it was not possible to transfer the PDOS-formatted data of nine patients (16 treatments) to MSDOS. Additionally, during the data processing by means of RHyThM (Rotterdam Hyperthermia Thermal Modulator), it was not possible to access temperature data of one patient (2 treatments) and 25 single treatments.

With these limitations, 48 patients (100 treatments) were available for analysis. Patients were grouped in four categories: male rectal cancer (n = 21 patients, 39 treatments), female rectal cancer (n = 14 patients, 27 treatments), cervical cancer (n = 8 patients, 21 treatments), and bladder cancer (n = 5 patients, 13 treatments). For a detailed description of patient characteristics and tumor stage see van der Zee et al. [11].

Hyperthermia

Hyperthermia was performed using the BSD-2000 with the Sigma-60 applicator (BSD Corporation, Salt Lake City, UT, USA) [10]. One to five (mean: four) locoregional hyperthermia treatments were delivered to the pelvis once weekly during the period of radiotherapy or chemotherapy. Hyperthermia was started at 400 W RF power. The treatment settings for frequency, amplitude distribution, and phase shifting at the start of the first treatment were selected according to the local protocol.

Patients were carefully instructed to mention any unpleasant sensation that might be the result of a hot spot [11]. Power output was increased to the patient's tolerance without pain. To improve the temperature distribution or to relieve pain complaints, treatment settings were adapted, i.e., phase, power per channel, frequency, or by placing additional water boluses. Treatment duration was 60 min after any of the intratumor-measured temperatures had reached 42 °C, or to a maximum of 90 min. Water bolus temperature was maintained at 20 °C. Systemic temperature was controlled by cooling measures: undressing, air-conditioning, wet towels, and ice packs. The bladder was kept empty with a Foley catheter [4].

Thermometry

Intratumor catheter placement was planned at least 1 day prior to the first hyperthermia treatment. 5 F polyethylene closed-tip thermometry catheter(s) (William Cook Europe ApS, Bjaeverskov, Denmark) were introduced in the tumor transgluteally under CT control. For details see van der Zee et al. [11]. Intraluminal catheters were inserted in bladder, rectum, and vagina lumen (as relevant) before each treatment. After catheter placement, the intratumor and intraluminal depths were documented. Insertion length of the intraluminal catheters was measured manually using a standard caliper. Bowman probes [1] were used to assess real-time temperature reading (accuracy: ± 0.1 °C). Temperature mapping was performed in 1 cm increments to a maximum length of 14 cm. Thermal mapping started just before the treatment and was repeated at 5-min intervals.

Data Processing and Definitions

The method of data processing has been extensively described by Fatehi et al. [3, 4]. In this study, the intratumor temperature is defined as temperature data acquired from within the tumor. The intraluminal temperatures are reported as normal tissue, tumor contact, tumor-indicative, or overall measurements. Tumor contact means that the catheter at the site of measurement lies in contact with tumor. When the site of

measurement is in the same transverse plane as the tumor, but not in contact with the tumor, the temperature is called tumor-indicative [13]. The remaining measurements represent normal tissue. The overall intraluminal temperature includes all measurements within one catheter; all lumina temperature includes all measurements within all intraluminal catheters, and the related lumen temperature refers to rectum lumen temperature for rectal cancer, to vagina lumen temperature for cervix cancer, and to bladder lumen temperature for bladder cancer patients.

Statistical Analysis

The statistical analysis was based on the temperature dose parameters, as provided in the ASCII files by RHyThM. Temperature measurements were available per patient, per treatment session, per probe, per mapping position, and per time point. All temperature measurements < 37 °C were excluded. The time points were scaled with respect to the starting time of the treatment. While computing averages, all observations were weighted equally.

The thermal dose parameters calculated per patient per treatment session were: average temperature (T_{mean}), T_{10}, and T_{90} (T_X means the temperature which is exceeded by X percent of all temperature readings). The averages and standard deviations were computed for all thermal dose parameters of different lumina (bladder, vagina, and rectum) and different tissue types (normal tissue, tumor indicative, tumor contact, and intratumor). Averages of intratumor and intraluminal temperatures were compared with t-tests. The p-values are two-sided at a significance level of $\alpha = 0.05$. STATA (version 9.2) was used for the statistical analysis.

Results

Intratumor Versus Intraluminal Temperatures

Temperature indices were calculated per patient, per treatment session and per time point from start until end of the treatment. Per patient per treatment, correlation coefficients were computed between intratumor and intraluminal tumor-indicative/tumor contact temperatures and between intratumor and intraluminal normal/all tissues temperatures. Averages of correlation coefficients between intratumor and intraluminal temperatures are presented in Table 1, and their relations are graphically summarized per treatment in Figure 1. Strong correlation was found between intratumor and intraluminal tumor contact/tumor-indicative temperatures in the four patient groups (average correlation coefficients vary from 0.91 to 0.96). In addition, good to strong correlation existed between intratumor and intraluminal normal/all tissues temperatures in the four patient groups (average correlation coefficients vary from 0.74 to 0.96).

Quantitative/Qualitative Temperature Analysis

For each group of patients, temperature indices were calculated per relevant tissue or relevant lumen and per time interval of 5 min. For each group of patients, a graph has been made which shows the relation between time and average temperature per relevant tissue or relevant lumen (Figure 2). An overview of average temperature indices in the four patient groups is given in Table 2.

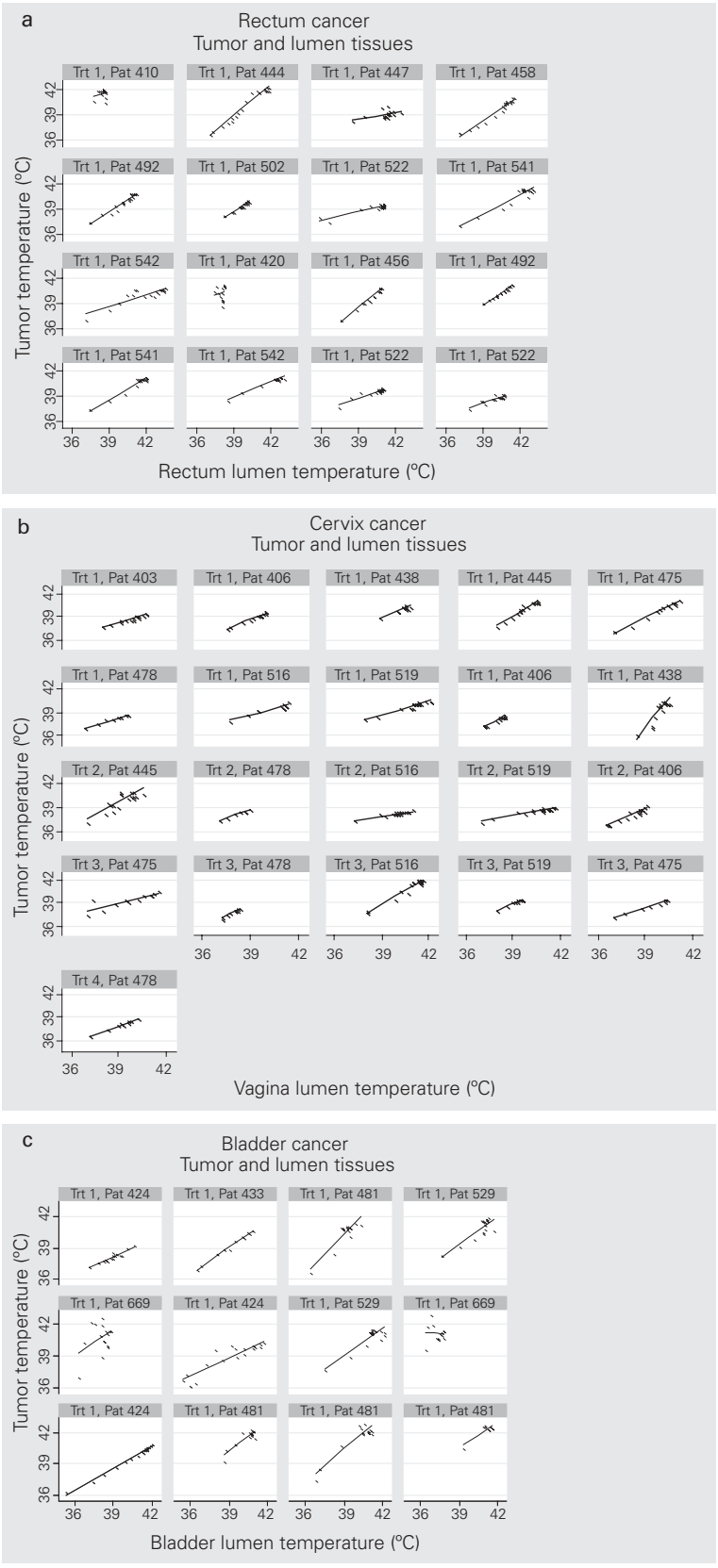
In the male rectal cancer group (Figure 2a), the average intratumor T_{mean} (40.3 ± 0.7 °C) was slightly lower than the averages of intraluminal rectum tumor indicative T_{mean}

Table 1. Slopes and correlation coefficients between averages of intratumor and intraluminal temperatures in the four patient groups as obtained in the study. Numbers in parentheses show 1 SD (standard deviation).

Tabelle 1. Steigungen und Korrelationskoeffizienten zwischen durchschnittlichen intratumoralen und intraluminalen Temperaturen in den vier Patientengruppen, wie in der Studie erreicht. Die Zahlen in Klammern zeigen 1 SD (Standardabweichung).

	Intratumor vs. intraluminal tumor contact[a]/tumor-indicative temperatures		Intratumor vs. intraluminal normal tissue temperatures		Intratumor vs. overall intraluminal temperatures in the related lumen[b]	
	Slope[c]	Correlation coefficient (1 SD)	Slope[c]	Correlation coefficient (1 SD)	Slope[c]	Correlation coefficient (1 SD)
Rectal cancer male (17 patient, 27 treatments)	0.80 (0.23)	0.95 (0.03)	0.61 (0.25)	0.81 (0.25)	0.70 (0.27)	0.80 (0.32)
Rectal cancer female (13 patients, 25 treatments)	0.84 (0.37)	0.95 (0.05)	0.77 (0.41)	0.85 (0.25)	0.74 (0.37)	0.88 (0.20)
Cervical cancer (6 patients, 18 treaments)	0.90 (0.67)	0.96 (0.03)	0.78 (0.27)	0.90 (0.16)	0.86 (0.44)	0.96 (0.04)
Bladder cancer (5 patients, 12 treatments)	0.84 (0.26)	0.91 (0.07)	0.66 (0.31)	0.74 (0.35)	0.76 (0.34)	0.79 (0.31)

[a]Tumor contact is used for the cervical cancer patients and tumor indicative for the rectal cancer patients. In the bladder cancer patients, the numbers are average for tumor contact and tumor indicative; [b]Related lumen temperature refers to rectum lumen temperature for rectal cancer patients, to vagina lumen temperature for cervix cancer patients, and to bladder lumen temperature for bladder cancer patients; [c]The analysis was based on Y = aX and "a" represents the slope. Slope < 1 means that intratumor temperature increases slower than intraluminal temperature and vice versa for slope > 1



Figurs 1a to 1c. Intratumor temperatures versus intraluminal rectum overall temperatures in rectum cancers (a), vagina overall temperatures in cervix cancers (b), and bladder overall temperatures in bladder cancers (c).

Abbildungen 1a bis 1c. Intratumorale Temperaturen versus intraluminale rektale Gesamttemperaturen bei Rektumkarzinomen (a), vaginale Gesamttemperaturen bei Gebärmutterhalskarzinomen (b) und vesikale Gesamttemperaturen bei Blasenkarzinomen (c).

($\Delta T = 0.2$ °C), rectum overall T_{mean} ($\Delta T = 0.2$ °C), and all lumina T_{mean} ($\Delta T = 0.1$ °C).

In the female rectal cancer patients (Figure 2b), the average intratumor T_{mean} (40.4 ± 0.8 °C) was lower than the averages of intraluminal rectum tumor-indicative T_{mean} ($\Delta T = 1.1$ °C), rectum overall T_{mean} ($\Delta T = 0.6$ °C), and all lumina T_{mean} ($\Delta T = 0.2$ °C).

In the cervix cancer group (Figure 2c), the average intratumor T_{mean} (39.4 ± 0.9 °C) was slightly lower than the averages of intraluminal vagina tumor contact T_{mean} ($\Delta T = 0.2$ °C), vagina overall T_{mean} ($\Delta T = 0.5$ °C), and all lumina T_{mean} ($\Delta T = 0.6$ °C).

In the bladder cancer patients (Figure 2d), the average intratumor T_{mean} (40.9 ± 1.1 °C) was slightly higher than the averages of intraluminal bladder tumor-indicative T_{mean} ($\Delta T = 0.2$ °C), bladder overall T_{mean} ($\Delta T = 0.6$ °C), and all lumina T_{mean} ($\Delta T = 0.4$ °C).

No significant difference was found between the intratumor and intraluminal temperatures in the four patient groups. Overall, the temperature measurements data were lowest in the cervical cancer patient group.

Intratumor Temperature Distributions

Temperature-time profiles per mapping position were computed for intratumor temperatures in each single treatment (Figure 3). We hypothesized that if SAR steering is effective in improving tumor temperature homogeneity, then the temperature time curves of a single treatment should show a homogeneous and preferable high temperature distribution. However, a clear improvement of temperature distribution was not seen in 26/27 treatments (96%) of male rectal cancers, and in 25/25 treatments (100%) of female rectal cancers. This was also the case for 94% (17/18 treatments) of cervical cancers, and 92% (11/12 treatments) of bladder cancers. The 18 remaining treatments had no more than one intratumor temperature point available for analysis.

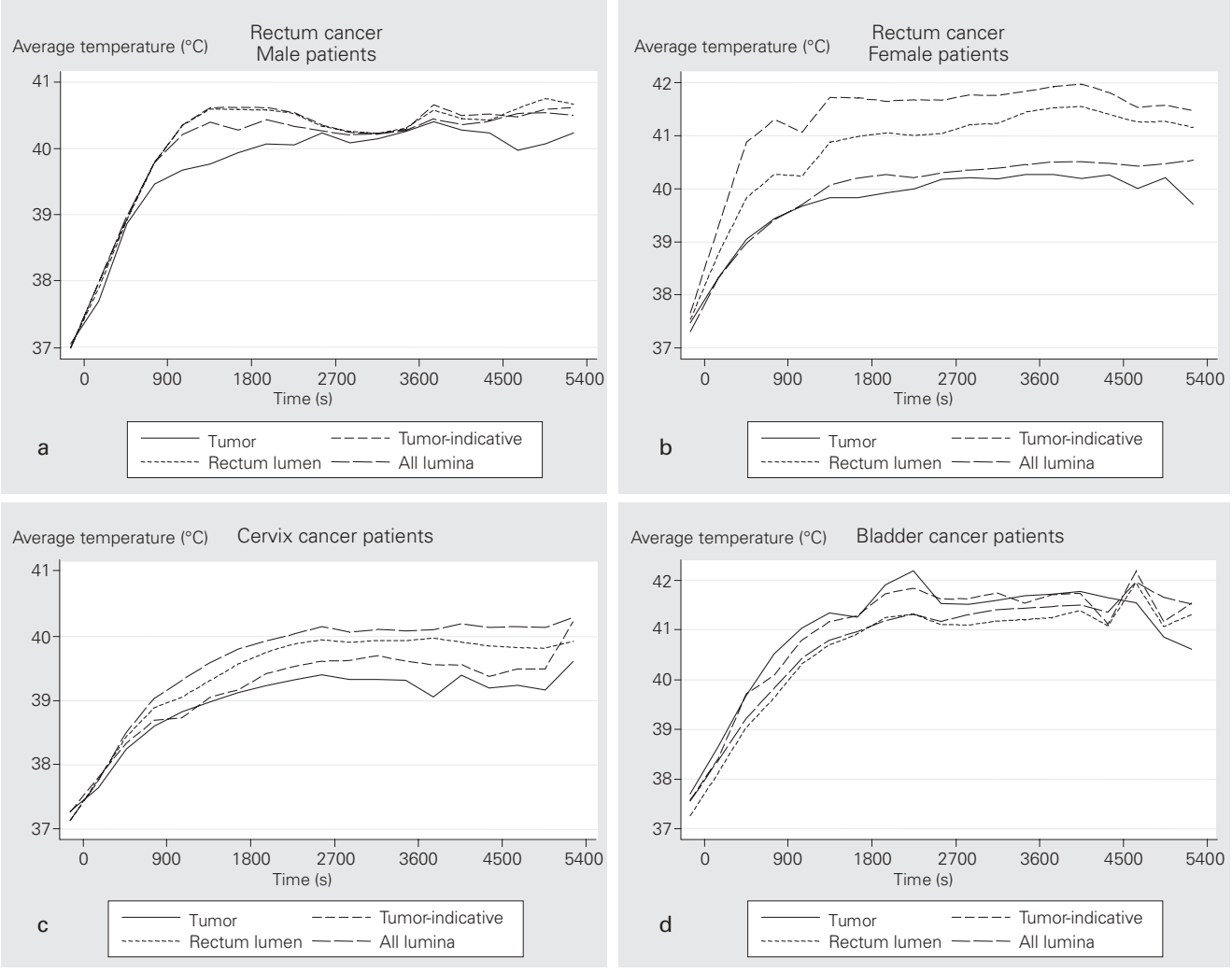
Discussion

Interstitial thermometry during locoregional hyperthermia is done for two main reasons: first, to apply the best possible treatment to the individual patient, by monitoring the achieved temperature level in a large tumor volume; second, for answering questions of more scientific nature, such as which equipment performs better in certain conditions, or which temperature increase pattern or thermal dose gives the highest probability of a good treatment result. In this study, we have focused on the question whether intraluminal temperature measurements provide sufficient information to apply hyperthermia at the maximum achievable level.

This study shows

(1) the temperatures achieved with the BSD-2000 in intrapelvic tumors are generally between 39.5 and 42 °C.
(2) there is a high correlation between temperatures measured intratumorally and intraluminally.
(3) the intratumor and intraluminal temperature-time profiles follow similar patterns. The later two findings mean that intraluminal temperatures can be used to monitor the change of intratumor temperatures.
(4) in 96% of treatments the intratumor temperature distribution pattern remains the same during 90 min of heating, in spite of SAR steering adjustments meant to improve the temperature distribution. This means the temperature distribution is insensitive to current SAR steering procedures. This is not a surprising result, since the used frequency of 70 MHz does not allow small-scale SAR steering.

There were five treatments where we found a poor correlation (< 0.7) between intratumor and intraluminal temperatures



Figurs 2a to 2d. Temperature-time profiles in male rectal cancer patients (a), female rectal cancer patients (b), cervical cancer patients (c), and bladder cancer patients (d).

Abbildungen 2a bis 2d. Temperatur-Zeit-Profile bei männlichen Patienten mit Rektumkarzinom (a), weiblichen Patienten mit Rektumkarzinom (b), Patientinnen mit Gebärmutterhalskarzinom (c) und Patienten mit Blasenkarzinom (d).

Table 2. Average of various temperature values (in °C) for the four patient groups. Numbers in parentheses show 1 SD (standard deviation).

Tabelle 2. Durchschnitt verschiedener Temperaturwerte (in °C) für die vier Patientengruppen. Die Zahlen in Klammern zeigen 1 SD (Standardabweichung).

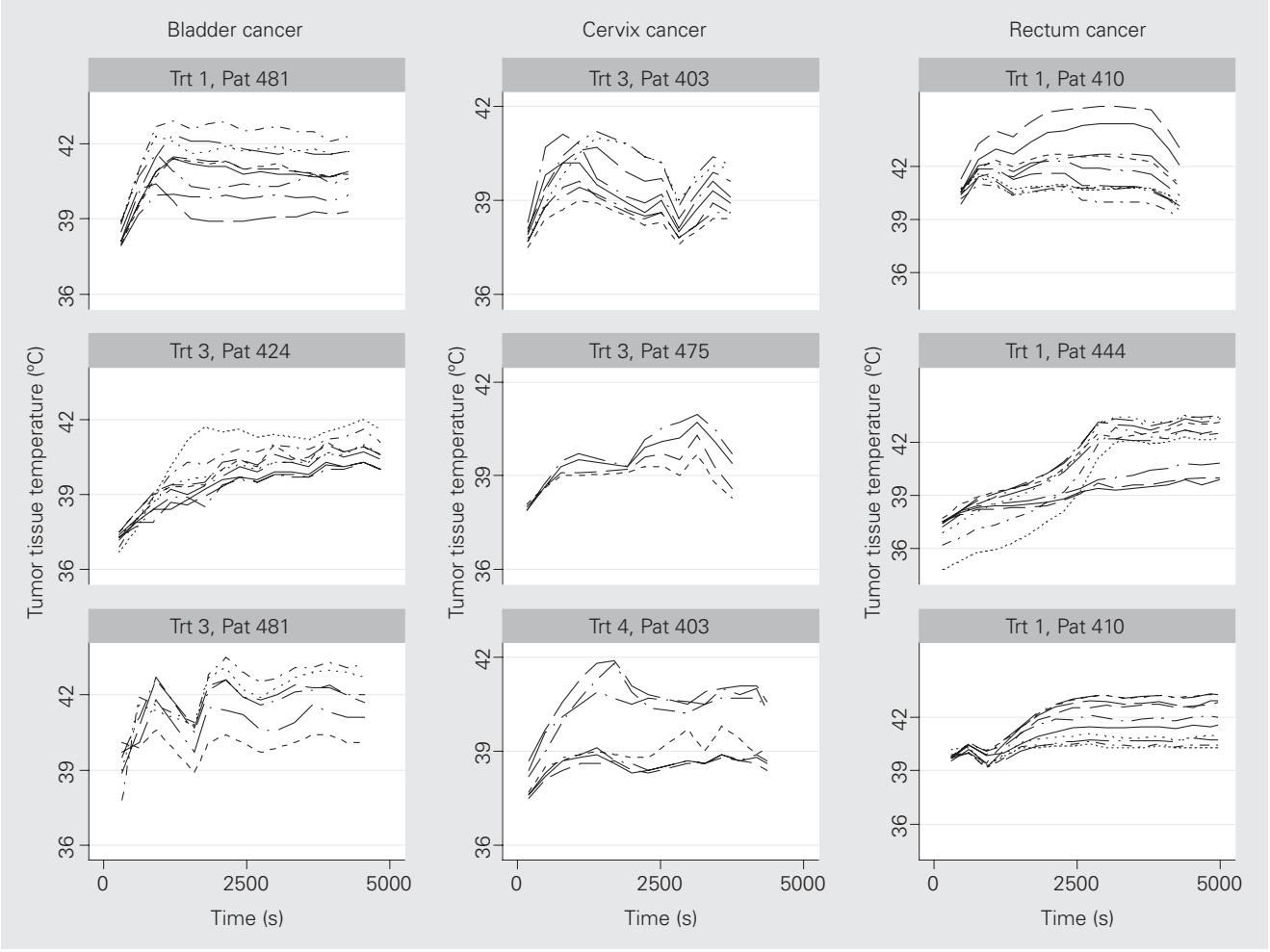
		Rectum cancer (males) (21 patients, 39 treatments)			Rectum cancer (females) (14 patient, 27 treatments)			Cervix cancer (8 patients, 21 treatments)			Bladder cancer (5 patients, 13 treatments)		
		T_{90}[a]	T_{mean}	T_{10}	T_{90}	T_{mean}	T_{10}	T_{90}	T_{mean}	T_{10}	T_{90}	T_{mean}	T_{10}
Tumor	Intratumor temperature	39.4 (0.7)	40.3 (0.7)	41.2 (1.1)	39.5 (0.8)	40.4 (0.8)	41.3 (1.1)	38.3 (1.0)	39.4 (0.9)	40.0 (1.0)	39.9 (1.0)	40.9 (1.1)	41.8 (1.2)
Bladder lumen	Normal tissue	39.3 (1.5)	40.2 (1.2)	41.0 (1.1)	39.7 (0.6)	40.3 (0.5)	41.0 (0.6)	39.4 (0.9)	40.3 (0.7)	41.1 (0.7)	39.1 (1.1)	39.8 (1.2)	40.5 (1.3)
	Tumor contact	–	–	–	–	–	–	–	–	–	39.3 (1.0)	40.4 (1.0)	41.4 (0.9)
	Tumor-indicative	39.6 (0.7)	40.2) (0.5)	40.9 (0.6)	39.8 (1.1)	40.4 (0.9)	41.0 (1.0)	39.3 (0.8)	40.1 (0.6)	40.8 (0.8)	39.5 (1.5)	40.7 (1.3)	41.7 (1.2)
	Overall	39.5 (1.1)	40.2 (0.9)	41.0 (0.9)	39.8 (0.9)	40.4 (0.7)	41.0 (0.8)	39.4 (0.9)	40.2 (0.7)	41.0 (0.8)	39.3 (1.2)	40.3 (1.2)	41.2 (1.1)
Vagina lumen	Normal tissue	–	–	–	39.6 (1.2)	40.3 (1.0)	41.1 (0.8)	39.4 (1.1)	40.1 (1.0)	40.9 (0.9)	40.0 (1.3)	40.7 (1.1)	41.3 (0.8)
	Tumor contact	–	–	–	39.7 (1.5)	40.4 (1.1)	41.0) (1.0)	38.9 (0.9)	39.6 (0.9)	40.3 (1.0)	39.7 (1.1)	40.5 (0.9)	41.4 (0.7)
	Overall	–	–	–	39.7 (1.4)	40.4 (1.1)	41.1 (0.9)	39.2 (1.0)	39.9 (1.0)	40.6 (0.1)	39.9 (1.2)	40.6 (1.0)	41.4 (0.8)
Rectum lumen	Normal tissue	39.8 (1.0)	40.5 (1.0)	41.1 (1.0)	39.6 (1.3)	40.5 (1.4)	41.4 (1.6)	39.2 (0.8)	40.0 (0.7)	40.9 (0.7)	39.8 (1.0)	40.4 (0.9)	41.0 (0.9)
	Tumor-indicative	39.7 (1.0)	40.5 (0.8)	41.3 (0.7)	40.8 (1.1)	41.5 (1.4)	42.2 (1.6)	39.2 (0.8)	39.9 (0.8)	40.4 (1.0)	39.9 (0.4)	40.5 (0.4)	41.1 (0.4)
	Overall	39.8 (1.0)	40.5 (0.9)	41.2 (0.9)	40.2 (1.2)	41.0 (1.4)	41.8 (1.6)	39.2 (0.8)	40.0 (0.8)	40.7 (0.9)	39.9 (0.7)	40.5 (0.7)	41.1 (0.7)
All lumina	Intraluminal temperature	39.6 (1.1)	40.4 (0.9)	41.1 (0.9)	39.9 (1.1)	40.6 (1.1)	41.3 (1.1)	39.2 (0.9)	40.0 (0.8)	40.7 (0.9)	39.7 (1.0)	40.5 (0.9)	41.2 (0.8)

[a] T_x means the temperature which is exceeded by X percent of all temperature readings

(Figure 1). For four treatments, we found a clear explanation for the discrepancy. In patients 410 (treatment 1), 420 (treatment 2) and 669 (treatments 1 and 2), the tumor was located excentrically near the iliac crest, so that the intraluminal temperatures were measured far from the tumor. These findings show that for treatment of tumors outside the region where intraluminal thermometry is possible, intratumoral thermometry is the only way to get information on treatment quality. Patient 447 (treatment 1) had the rectal ampulla filled with feces during the first treatment, which may explain the much higher rectal temperatures compared to intratumor temperatures.

These results confirm the clinical impression that intratumor thermometry does not add to the quality of treatment when the BSD-2000 system is used for treatment of intrapelvic centrally located tumors, and that intraluminal temperature measurements are sufficient to apply the best possible treatment to the individual patient [11]. Wust et al. came to the same conclusion, based on an analysis of relations between intraluminal and intratumoral SAR measurements in patients with cervical and rectal cancer [16]. Elsewhere, Hoffmann et al. [5] reported rectal temperatures with MRI like those found in the present study. Likewise, Wust et al. [15] and Sreenivasa et al. [8] recently found that intraluminal temperatures are related to the response probability. There are no reasons to assume that this result will be different for other equipment using radiative electromagnetic heating at frequencies between 70 and 120 MHz and SAR control by phase and amplitude steering.

Whether it is justified to use intraluminal thermometry only during treatment of intrapelvic tumors appears a matter of institute's priorities. We agree with Sneed et al. who state that the only way to calculate tumor thermal dose is to measure the tumor temperature directly [7]. Intraluminal thermometry reflects, but is not equal to intratumor thermometry. However, whether this is important depends on the aim of the measurements, especially taking the disadvantages of intratumor thermometry into account: time consuming, stressful and



Figurs 3. Examples of the intratumor time-temperature profiles per mapping position in different cancer groups.

Abbildung 3. Beispiele der intratumoralen Zeit-Temperatur-Profile pro Mapping-Position in den verschiedenen Karzinomgruppen.

painful to the patient, and severe side effects (bleeding, infection, tumor seeding, etc.). We find thermometry important for the application of hyperthermia at the maximum achievable temperature levels. For this aim, intraluminal thermometry is sufficient. In our experience, intratumor thermometry was the major cause of treatment related toxicity [11]. Introduction of thermometry catheters before each separate treatment session may decrease the complication rate, but it remains an unpleasant, time consuming and costly procedure. The results of the detailed temperature analysis presented here and the latest publication of Wust et al. [15] and Sreenivasa et al. [8] support our earlier decision to abandon intratumor thermometry. Of course, this discussion becomes redundant when noninvasive thermometry is widely available [12].

Conclusion

The high correlations between intraluminal and intratumor temperatures and the current lack of possibilities to improve intratumor temperature distribution by SAR steering justify to guide deep regional hyperthermia application to centrally located tumors in the lesser pelvis with intraluminal thermometry only.

Acknowledgments

This work was supported by the Dutch Cancer Society grant 2003-2884. The first author was supported financially by the Shahrekord University of Medical Sciences (related to the Iranian Ministry of Health, Treatment and Medical Education).

References

1. Bowman R. A probe for measuring temperature in radio frequency heated material. IEEE Trans MTT 1976;24:43–5.
2. Dunst J, Diestelhorst A, Kuhn R, et al. Organ-sparing treatment in muscle-invasive bladder cancer. Strahlenther Onkol 2005;181:632–7.
3. Fatehi D, de Bruijne M, van der Zee J, et al. RHyThM, a tool for analysis of PDOS formatted hyperthermia treatment data generated by the BSD2000/3D system. Int J Hyperthermia 2006;22:173–84.

4. Fatehi D, van der Zee J, van der Wal E, et al. Temperature data analysis for 22 patients with advanced cervical carcinoma treated in Rotterdam using radiotherapy, hyperthermia and chemotherapy: a reference point is needed. Int J Hyperthermia 2006;22:353–63.
5. Hoffmann KT, Rau B, Wust P, et al. Restaging of locally advanced carcinoma of the rectum with MR imaging after preoperative radio-chemotherapy plus regional hyperthermia. Strahlenther Onkol 2002;178:386–92.
6. Kim TH, Kim DY, Cho KH, et al. Comparative analysis of the effects of belly board and bladder distension in postoperative radiotherapy of rectal cancer patients. Strahlenther Onkol 2005;181:601–5.
7. Sneed PK, Dewhirst MW, Samulski TV, et al. Should interstitial thermometry be used for deep hyperthermia? Int J Radiat Oncol Biol Phys 1998;40:1015–7.
8. Sreenivasa G, Hildebrandt B, Kummel S, et al. Radiochemotherapy combined with regional pelvic hyperthermia induces high response and resectability rates in patients with nonresectable cervical cancer >/= FIGO IIB "bulky". Int J Radiat Oncol Biol Phys 2006;66:1159–67.
9. Tilly W, Gellermann J, Graf R, et al. Regional hyperthermia in conjunction with definitive radiotherapy against recurrent or locally advanced prostate ancer T3 pN0 M0. Strahlenther Onkol 2005;181:35–41.
10. Turner PF, Schaefermeyer T. BSD 2000 approach for deep local and regional hyperthermia: clinical utility. Strahlenther Onkol 1989;165:700–4.
11. Van der Zee J, Peer-Valstar JN, Rietveld PJM, et al. Practical limitations of interstitial thermometry during deep hyperthermia. Int J Radiat Oncol Biol Phys 1998;40:1205–12.
12. Van Rhoon GC, Wust P. Introduction: non-invasive thermometry for thermotherapy. Int J Hyperthermia 2005;21:489–95.
13. Wielheesen DHM, de Bruijne M, Graveland WJ, et al. Leg coverage with towels during regional deep hyperthermia treatment and its effect on pelvic temperature and temperature distribution. Int J Hyperthermia 2005;21:77–87.
14. Windschall A, Ott OJ, Sauer R, et al. Radiation therapy and simultaneous chemotherapy for recurrent cervical carcinoma. Strahlenther Onkol 2005; 181:545–50.
15. Wust P, Cho CH, Hildebrandt B, et al. Thermal monitoring: invasive, minimal-invasive and non-invasive approaches. Int J Hyperthermia 2006; 22:255–62.
16. Wust P, Gellermann J, Harder C, et al. Rationale for using invasive thermometry for regional hyperthermia of pelvic tumors. Int J Radiat Oncol Biol Phys 1998;41:1129–37.

Address for Correspondence
Daryoush Fatehi, M.Sc.
Unit Hyperthermia
Department of Radiation Oncology
Erasmus Medical Center
Daniel den Hoed Cancer Center
PO Box 5201
3008 AE Rotterdam
The Netherlands
Phone (+31/10) 4391-654, Fax -022
e-mail: d.fatehi@erasmusmc.nl