

Renal Tumor Cryoablation Planning. The Efficiency of Simulation on Reconstructed 3D CT Scan

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Abstract

Introduction & Objective: Nephron-sparing surgical techniques risks are related to tumor relationships with adjacent anatomic structures. Complexity of the renal anatomy drives the interest to develop tools for 3D reconstruction and surgery simulation. The aim of the article was to assess the simulation on reconstructed 3D CT scan used for planning the cryoablation. *Material & Method:* A prospective randomized study was performed between Jan. 2007 and July 2009 on 27 patients who underwent retroperitoneoscopic T1a renal tumors cryoablation (RC). All patients were assessed preoperatively by CT scan, also used for 3D volume rendering. In the Gr.A, the patients underwent surgery planning by simulation on 3D CT scan. In the Gr.B., patients underwent standard RC. The two groups were compared in terms of surgical time, bleeding, postoperative drainage, analgesics requirement, hospital stay, time to socio-professional reintegration. *Results:* Fourteen patients underwent preoperative cryoablation planning (Gr.A) and 13 patients underwent standard CR (Gr.B). All parameters analyzed were shorter in the Gr.A. On multivariate logistic regression, only shortens of the surgical time (138.79 ± 5.51 min. in Gr.A. vs. 140.92 ± 5.54 min in Gr.B.) and bleeding (164.29 ± 60.22 mL in Gr.A. vs. 215.38 ± 100.80 mL in Gr.B.) achieved statistical significance ($p < 0.05$). The number of cryoneedles assessed by simulation had a 92.52% accuracy when compared with those effectively used. *Conclusion:* Simulation of the cryoablation using reconstructed 3D CT scan improves the surgical results. The application used for simulation was able to accurately assess the number of cryoneedles required for tumor ablation, their direction and approach.

Keywords: Cryosurgery; Renal tumor; Nephron-sparing surgery.

Introduction

Assessment of the risks related to nephron-sparing surgical techniques should consider besides the tumor size, also the tumor relationship with anatomic structures from the renal sinus [1].

Although, open partial nephrectomy is considered the golden standard for small renal tumors (T1a), guidelines stress that this nephron-sparing technique may not be recommended in every case due to technical particularities [2].

Minimal invasive techniques have limitations due to smaller working space and reduced degrees of freedom characteristic for the design of the laparoscopic instruments. Thus, the laparoscopic or retroperitoneoscopic partial nephrectomy is multifactorial related to tumor size but also to its location, relationship with anatomic renal structures and availability of a direct approach [3].

PADUA ("preoperative aspects and dimensions used for anatomical") classification was intended to assess the main preoperative factors related to the surgical risks associated with the partial nephrectomy for small renal tumors [1].

Complexity of the renal anatomy drives the interest to develop tools for 3D reconstruction and stereoscopic virtualization able to provide the means for planning and assessing the feasibility and risks of the surgery [4].

The aim of the article was to assess the simulation on reconstructed three dimensional CT scan used for planning the renal tumor cryoablation.

Material and Method

Study design

A prospective study was performed between January 2007 and July 2009 on 27 patients who underwent retroperitoneoscopic T1a renal tumors cryoablation. All patients were assessed preoperatively by enhanced spiral CT scan (Siemens 64 slice Somatom Sensation). The CT slices were used for three dimensional (3D) volume rendering. The patients were randomly distributed in two groups. In the Gr.A, the patients underwent planning of the surgery by simulation of the cryoablation on individualized reconstructed 3D CT scan. Renal tumor cryoablation was done without prior planning for the patients from Gr.B. The two groups were compared in terms of surgical time, bleeding, postoperative drainage, analgesics requirement, hospital stay, time to socio-professional reintegration. For all patients, the number of cryoneedles was assessed by simulation on reconstructed 3D CT scan and compared with the number effectively used.

Renal tumor cryoablation procedure and its simulation on reconstructed 3D CT

The retroperitoneoscopic cryoablation procedure was described in a previous paper [5].

Cryoablation simulation was done using an application developed as part of the CrioLapSim research project in partnership between Clinical Institute of Urology and Renal Transplantation and the Computer Science Department of the Technical University of Cluj-Napoca. The simulation was done using an implementation of the DicomTools application which allows qualitative and quantitative assessment of the cryoneedles setting, evolution of the temperature map. The application allows using of an oblique plan, which could be set perpendicular to the direction of the cryoneedles.

After processing the CT slices, the region of interest is selected to include the affected kidney and the tumor. A 3D surface of the reconstructed volume is created and visualized in the whole body CT scan (Figure 1.).

Following identification of the ideal oblique plan, the cryoablation volumes corresponding to the -20°C isotherm and a 20 mm size, generated by every cryoneedle, are placed to cover the whole tumor volume.

The planning of the cryoablation is presented in Figure 2.

The 3D reconstruction was also used for planning the surgical approach, the extension of the perirenal dissection, the direction and number of the cryoneedles required for the procedure.

Statistical analysis

Parametric continuous variables are given as the mean plus or minus standard deviation and categorized according to the median value. The efficiency of the simulation on reconstructed 3D CT scan was assessed by logistic regression. A $p < 0.05$ was considered statistically significant. All data were analyzed with the EpiInfo™, Version 3.5.1 (National Center for Public Health Informatics, USA).

Results

Fourteen patients underwent preoperative cryoablation planning using reconstructed 3D CT model (Gr.A) and 13 patients underwent renal tumor cryoablation without prior surgery planning (Gr.B).

All parameters analyzed were shorter in the Gr.A (Table 1.). On multivariate logistic regression, only shortens of the surgical time and bleeding achieved statistical significance (Table 2.), for $p < 0.05$.

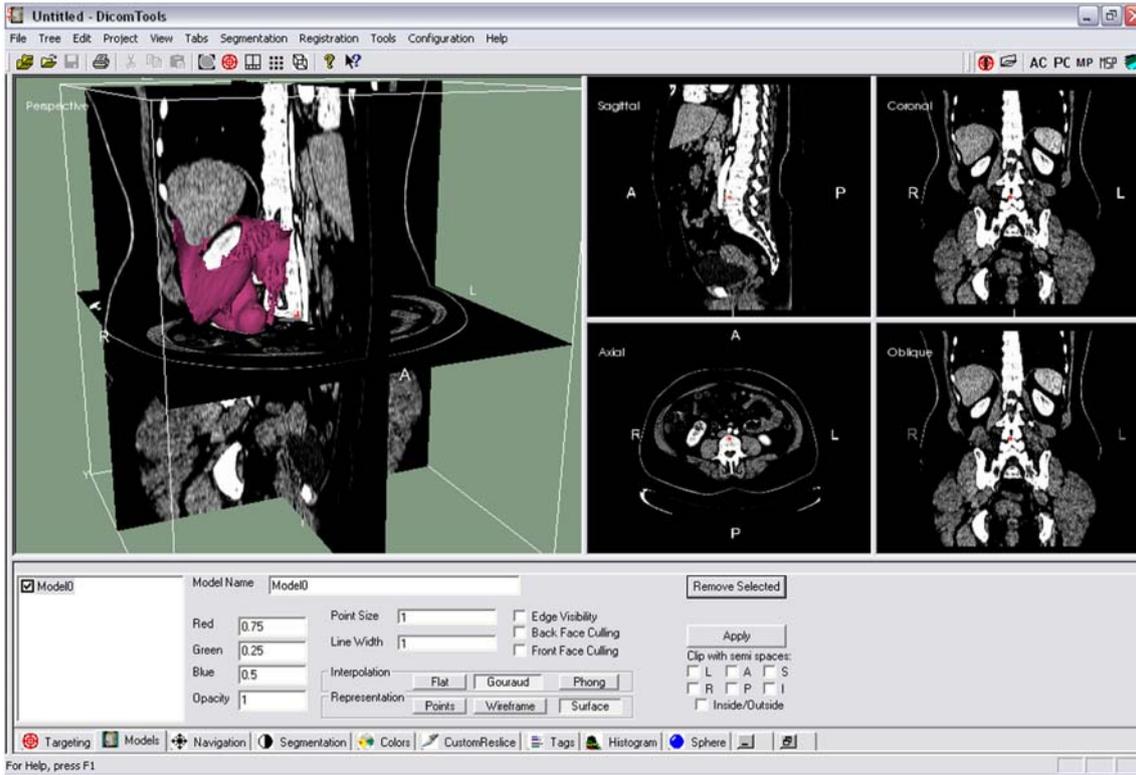


Figure 1. The region of interest has been used to generate the 3D reconstructed surface, displayed in the thoraco-abdominal CT scan.

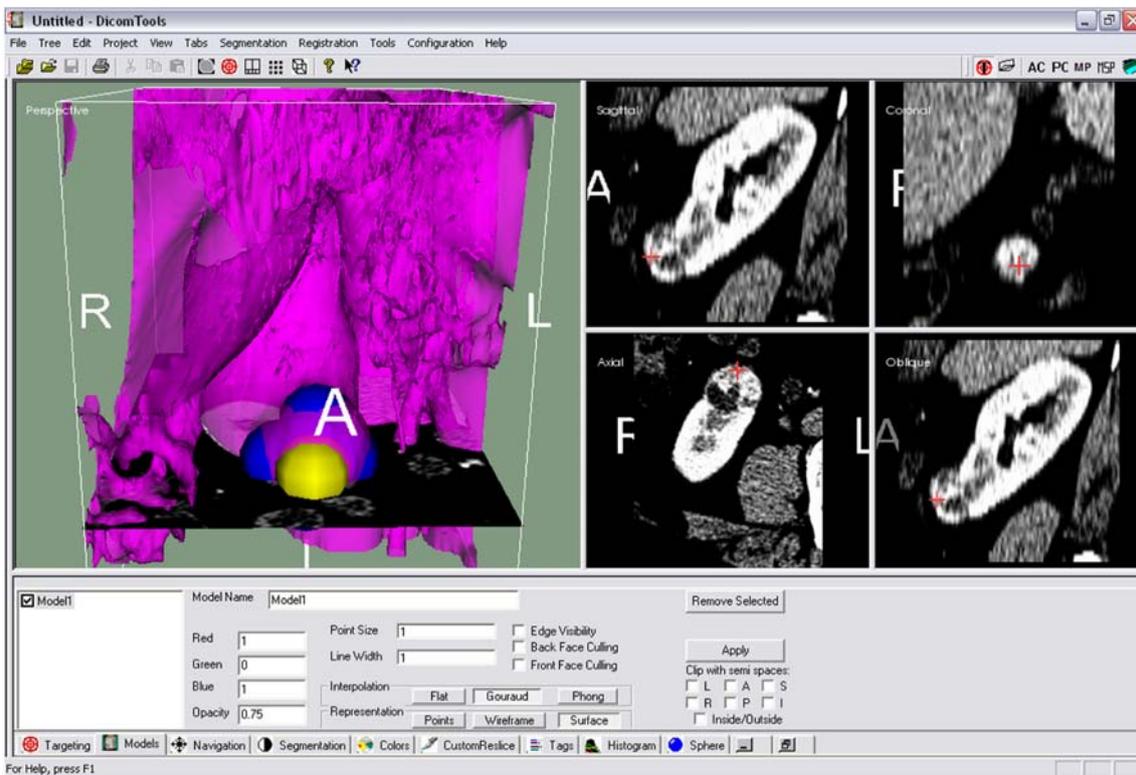


Figure 2. Planning of the cryoablation. The tumor volume is included by the summed volume of the ice balls, corresponding to the isotherm of -20°C and a diameter of 2 cm.

Table 1. Main results

	Gr.A	Gr.B
Number of patients	14	13
Surgical time (min.)	138.79±5.51	140.92±5.54
Bleeding (mL.)	164.29±60.22	215.38±100.80
Postoperative drainage (mL.)	80.36±22.31	98.08±18.99
Analgesics requirements (mg equivalent morphine sulphate)	10.36±4.55	11.53±3.67
Hospital stay (days)	5.5±2.38	5.69±2.25
Socio-professional reintegration (days)	13.93±4.34	14.85±4.10

Table 2. Multifactorial logistic regression

Regression parameters	Beta	Std. Err. of Beta	B	Std. Err. of B	t(19)	p-level
Intercept			93.295	3.396	27.472	0.000
Tumor volume (cm ³)	0.082	0.201	0.001	0.002	0.406	0.689
Surgical time (min.)	0.579	0.274	0.053	0.025	2.112	0.048
Bleeding (mL)	0.631	0.264	0.004	0.002	2.385	0.027
Postoperative drainage (mL)	0.269	0.208	0.006	0.005	1.291	0.212
Analgesics requirements (mg equivalent morphine sulphate)	-0.270	0.225	-0.033	0.028	-1.199	0.245
Hospital stay (days)	-0.321	0.262	-0.072	0.059	-1.226	0.235
Socio-professional reintegration (days)	0.102	0.202	0.013	0.025	0.506	0.618

N=27, R=0.61733663, R²=0.38110451, Adjusted R²=0.15309039, F(7,19)=1.6714, p<0.17611, Std.Error of estimate: 0.46858

The number of cryoneedles was assessed by simulation on reconstructed 3D CT scan with a 92.52% accuracy when compared with those effectively used. The average tumor size, in regard with the number of cryoneedles used, is presented in Table 3.

Table 3. Relation between tumor size and number of cryoneedles planned preoperatively.

Nr. cryoneedles	Nr. Patients	Tumor size (cm)		Tumor volume (cm ³)	
		average	range	average	range
1	8	1.49±0.36	1-2	8.98±5.94	2.4-18.8
3	5	2.38±0.16	2.2-2.5	32.12±6.42	25.1-36.8
4	5	2.72±0.13	2.6-2.9	47.68±6.93	41.4-57.5
5	4	3.13±0.05	3.1-3.2	71.95±3.51	70.2-77.2
6	1	3.8		129.29	
7	4	4±0.17	3.8-4.2	148.6±19.41	129.3-174.6
Total	27	2.58±0.91		54.9±49.35	

Discussion

Minimal invasive nephron sparing surgery is challenging regardless the specific technique involved. Experience is a key point to feasibility and efficiency but knowing the specific anatomic characteristic allows proper indications and may improve the surgery and the patient's outcome.

Considering 6 studies on laparoscopic partial nephrectomy [3,6-11], renal hilar vessels clamping was required only in four studies in a proportion varying between 45% to 99%, while average tumor size vary between 1.9 cm to 2.9 cm. Also, the complication rate varies largely from 10% to 33%. An explanation for a such variability of the results may be due to other factors than simply tumor size [11].

Preoperative assessment of the kidney and tumor improved over time due to progresses in imaging techniques [12]. With increased resolution of the CT, MRI and ultrasound imaging, development of the computer processing allows 3D applications to be developed. It looks like exploring the anatomy did not require cutting any more [13,14].

At present, there are many software and hardware solutions for 3D CT reconstruction but such instruments are used mainly by those involved in imaging diagnosis and only for limited purposes by those who treat. Many applications are dedicated to various types of radiotherapy and less to surgical treatment.

A specific attention was paid to renal vasculature in the case of planning the partial nephrectomy. For such purpose, 3D CT imaging proves utility but vessels are not the only aspects of interest [13]. The correct approach to the kidney and tumor, the tumor relation to the calyx may also contribute to less complications and a better outcome after nephron sparing surgery.

The application used in this study allows specifically planning the surgery with significantly reduced surgical time and bleeding. The software allows establishing the extension of the perirenal dissection, the direction and approach points for cryoneedles placement and assessing the particular number of cryoneedles required for a specific tumor.

The application was customized for different cryoneedle in regard with the producer specifications.

The number of cryoneedles required was related to tumor size: one for tumors less than 2 cm, 3 for tumor size between 2 to 2.5 cm, 4 cryoneedles for tumors up to 3 cm, 5 for tumors 3 to 3.5 cm and 6-7 cryoneedles for tumors up to 4 cm.

Conclusions

Simulation of the cryoablation using reconstructed 3D CT scan improves the surgical results. The application used for simulation was able to accurately assess the number of cryoneedles required for tumor ablation, their direction and approach.

Ethical Issues

The study was approved by the local comity of ethics and considered beneficial to the patient since the use of simulation may add valuable data for procedure planning, and the surgical protocol was not changed in the absence of simulation.

Conflict of Interest

The patients give the informed consent for participating in the study, with respect of the confidentiality. The author declares that he has no conflict of interest.

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