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Three-dimensional visualization and virtual simulation of resections in pediatric solid tumors

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Abstract
Purpose: Three-dimensional visualization of solid tumors is possible because of high-resolution computed tomography and magnetic resonance imaging scans. However, additional preoperative information is often desirable in complex malignancies. For the first time, the authors present a model of preoperative 3-dimensional visualization and virtual resections in pediatric solid tumors.
Methods: Image analysis of various pediatric tumors was performed using the research software HepaVision2 (MeVis, Bremen). Organs, tumors, and the vascular system were extracted from multislice computed tomography scans. After hierarchical analysis of the vascular system, territories supplied or drained by the major vascular branches were calculated. Results were explored and virtual resections of organs were carried out using the research software InterventionPlanner (MeVis, Bremen). Data were correlated to intraoperative findings.
Results: Four hepatic malignancies, 4 renal tumors, and 3 other neoplasms were analyzed. The technique of 3-dimensional visualization was feasible for all investigated children (mean age 5 years and 9 months). Spatial relations between physiological and pathological structures were identified, and anatomical structures (vessels, tumor tissue, and organ parenchyma) were determined using colorimetric encoding. Virtual simulations of tumor resection were used successfully for planning of surgical procedures in the hepatic and renal tumors.
Conclusions: The technique of 3-dimensional tumor visualization and virtual simulation of tumor resections provides the basis for a successful planning of complex tumor resections in children. The efficiency of these techniques should be further analyzed in series with higher numbers and differentiations of tumors.

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1. Background

Surgical resection is a key factor in the treatment of many pediatric solid tumors. The preoperative tumor evaluation and planning of surgical strategies are commonly based on ultrasound imaging, computed tomography, and magnetic resonance imaging scans [1]. The introduction of spiral CT added new opportunities to the analysis of tumors, giving higher resolution, advanced volumetric assessments, as well as lower investigation times and radiation [2]. However, some information cannot be retrieved from original data and intraoperative procedures have to be altered in numerous cases. Furthermore, conventional imaging techniques do not allow precipitation of surgical resections and analyses of their impact on the remaining parenchyma.

HepaVision2 (MeVis, Bremen) is a software tool specifically developed for image analysis and risk analysis of the liver. Based on raw data from multislice computed tomography, visualization of various anatomic sites can be performed [3]. The software assistant InterventionPlanner uses the acquired and analyzed data for simulation of different surgical procedures. For example, liver resections can be virtually performed by hiding selective areas of the portal venous drainage or creating resection surfaces in the patient-individual 3D model [4].

The aim of our study was to assess the impact of the software assistants HepaVision2 and InterventionPlanner on the planning of surgical procedures in pediatric patients suffering from solid tumors.

2. Materials and methods

2.1. Patients

From June 2003 to May 2004, 11 children with solid tumors were analyzed before surgical intervention at our institution (Table 1). Mean age at the time of CT scan was 5 years and 9 months (from 18 months to 18 years and 8 months). All patients except one received preoperative chemotherapy according to the respective treatment studies from the International Society of Pediatric Oncology or the German Society of Pediatric Oncology [4-6]. The patient who suffered from the pseudopapillar pancreatic tumor did not receive chemotherapy as this approach does not contribute to a more favorable outcome in this particular tumor entity.

2.2. Computed tomography

All imaging was carried out on a multislice helical CT scanner (Volume Zoom Sensation 16, Siemens, Erlangen, Germany) with a 0.5-second gantry rotation. The scanning parameters were as follows: 120 kVp, 30 to 85 mA · s adapted to the bodyweight, 16 × 0.75 mm collimation, 12 mm table feed per rotation, slice thickness 0.75 mm, increment 0.5 mm.

All children received contrast material (Imeron 400, Bracco-Byk Gulden, Germany) for biphasic examination. Contrast material was administered by power injector (Stellant, Medrad, Germany) at 1.2-3.0 mL/s using either a 22- or 24-gauge needle placed in an antecubital vein. Bolus tracking was used for optimal analyses with contrast medium during the biphasic examinations. Therefore, a region of interest was defined within the abdominal aorta. Serial low dose scanning was performed, and the actual scan was started when a threshold of 120-130 HU was reached within the defined region.

2.3. Visualization and virtual tumor resection

Image analysis consists of several processing steps as described before by Bourquain et al [3]. The entire computer-aided evaluation has 2 parts. Part 1, image analysis consisting of (*a*) segmentation of the respective organ, that is, extraction of the organ from CT data; (*b*) segmentation and structural analysis of the vascular systems such as portal vein, hepatic veins, hepatic arteries renal arteries, and others; (*c*) calculation of supplied or drained territories; (*d*) volumetry of liver, kidney, or designated territories. Part 2, surgical planning and risk analysis consisting of (*a*) definition of cutting lines, both automatically proposed and manually modified; (*b*) risk analysis with calculation of

Table 1 Patients' data

Patient No.	Diagnosis	Age at CT	Surgical procedure
1	Hepatoblastoma	18 mo	Trisegmentectomy right
2	Hepatoblastoma	2 y 8 mo	Trisegmentectomy right
3	Hepatoblastoma + lung metastases	5 y 1 mo	Trisegmentectomy left and sternotomy
4	Hepatic fibrosarcoma	18 y 8 mo	Tumor considered inoperable
5	Unilateral Wilms' tumor	3 y 4 mo	Tumor nephrectomy
6	Unilateral Wilms' tumor	4 y 3 mo	Tumor heminephrectomy
7	Unilateral Wilms' tumor + lung metastases	24 mo	Tumor nephrectomy
8	Unilateral Wilms' tumor	20 mo	Tumor nephrectomy
9	Carcinoma of the pancreas + liver metastases	9 y 8 mo	Whipple, metastasectomy (cardiac arrest + bypass)
10	Solid pseudo-papillary tumor of the pancreas	11 y 4 mo	Whipple procedure
11	Pelvic rhabdomyosarcoma + lung metastases	2 y 11 mo	Radical tumor resection, Mitrofanoff, sternotomy

Lung metastases in patient 7 were resected in a second approach; cardiopulmonary bypass in patient 9 was performed because of ante situ resection of liver metastases; for patient 4 see text.