Clinical Relevance of Preoperative CT- based Computer Aided 3D- Planning in Hepatobiliary, Pancreatic Surgery and Living Donor Liver Transplantation

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***Abstract*—These Multiple imaging approaches are currently used for diagnosis and surgery planning of hepatobiliary tumors and living donor liver transplantations. Conventional imaging studies remain insufficient to demonstrate the individual anatomy. Refinements in CT technology with the introduction of «multidetector-row» CT scanners and implementation of mathematical methods on computerized digital data enabled CT based 3D- visualizations. This renders preoperative surgery planning more reliable and reproducible. Since the application in oncological liver surgery has been studied previously, our interest focussed on pancreatic- and biliary tract tumors including preoperative work-up in living donor liver transplantation. A total of 29 patients were assessed. CT based 3D- display provided accurate preoperative visualization and computerized risk analyses for safety margins of pancreatic- and biliary- tract tumors. In living related liver transplantation the 3D- procedure may help to recognize vascular variants and to define the splitting line. The results may have major impact on patient selection and in our opinion allow better planning of the appropriate surgical approach.**

I. Introduction

Hepatobiliary- and pancreatic surgery as well as liver transplantation have shown considerable developments, mainly due to improvements of surgical techniques, diagnostic imaging modalities and postoperative care. Recent developments of imaging techniques with the implementation of computer technologies have enabled a new quality of visualization consisting in 3D- representation to realize image guided and computer assisted surgery. These developments allow enhanced precision in preoperative planning and image guided surgery using intraoperative navigation tools. This is already practiced in neuro-, maxillo-facial and orthopaedic surgery .

3D- visualizations of visceral organs failed in the past because of technological limitations to create image data with minimal motion artifacts and lack of stable computerized image processing technologies. The introduction of «multidetector- row» helical CT, however, has offered the opportunity to create digital data with minimal motion artifacts [1]. The application of a variety of dedicated and robust computerized image processing steps succeeded in visualizations, which enable precise localization and exact in- depth representation of tumors especially in surgery of liver cancers [2,3]. Because of limited availability of postmortal liver donors, the challenging technique of living related liver donor transplantation (LDLT) has gained increasing application worldwide. Especially this field reinforced the interest in computerized preoperative 3D- visualizations. Adult-to-adult LDLT is technically demanding. The liver has to be splitted into in a well preserved right lobe representing the graft and a remnant left liver lobe without any damage to the donor. To achieve these aims accurate anatomical and functional work- up for surgical planning is mandatory. The same holds true for planning of oncological resections in biliary- and pancreatic tumors. To analyze the clinical impact of computerized 3D- visualizations in hepatobiliary – pancreatic surgery and LDLT we performed a collaborative study with the IT- research institute MeVis, Bremen , Germany.

II. Material and Methods

A total of 29 patients were assessed by CT based 3 D- visualization techniques. 12 patients were analysed for pancreatic-, 4 patients for biliary tract tumors and 13 patients for LDLT. CT scans were performed with a 4 slice «multirow-detector» helical scanner machine (Siemens Volume Zoom®, Siemens Erlangen ,Germany). For computer assisted 3D- viszualisation data were transferred to the IT- Research Institute MeVis, Bremen, Germany. 3D- image processing of original CT- data included segmentation of specific anatomic and pathologic structures. For relevant vascular structures centre lines were calculated. A hierachical mathematical model representing the vascular tree was created. This allowed calculation of individual vascular territories. Computerized “surgery planning” included virtual insertion of splitting lines in LDLT and safety margins in oncologic patients**.** Results were displayed either one by one or in arbitrary combinations in both, 3D- and overlayed to the original CT data [2,3].

III. Experiments and Results

Pancreatic Tumors: 3D- visualization of pancreatic tumors succeeded in 11 of 12 cases. In a single case of cancer of the papilla of Vater with the tumor mass localized within the duodenum visualization was unsatisfactory. In 2 patients arterial variants of the common hepatic artery originating from the superior mesenteric artery could be displayed. Visualization of vascular structures in

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the vicinity of the tumor succeeded in all cases. Involvement of regional arteries by the tumor (A. gastroduodenalis n= 3, SMA n= 1, Celiac trunk n= 1, A. lienalis n=1) and/ or of the venous mesenterico- portal trunk (portal vein n= 1, confluens n= 2, SMV n= 1, V. lienalis n= 1) could be shown in 5 patients. On the basis of computerized surgery planning, resection of the tumor seemed likely in 9 cases. Operative procedures for cure were performed in 9 patients. Palliative surgery was carried out in 2 patients because of multivisceral tumor infiltration. In all patients the specific findings (tumor size, localization, vascular involvement) obtained by 3D– CT visualization could be reconfirmed intraoperatively. Because of non-resectability one patient was treated with palliative chemotherapy.

Biliary-Tract Tumors: 3D- CT based visualizations demonstrated localization, extraluminal extend and involvement of adjactend vascular structures within the liver hilum and the hepatoduodenal ligament. Longitudinal ductal tumor extension could be demonstrated as well. ERC- and MRC- examination revealed biliary- tract tumors classified as Bismuth type IV in 1, Bismuth type I in 2 and tumor of the distal common hepatic duct in one case. 3D- CT based visualizations were discrepant in 2 cases. ERC- and MRC classified Bismuth type I tumors appeared as Bismuth type II/IIIa in 1 and as a tumor originating from the gall bladder in 1 case. Compared to conventional radiological methods, 3D- CT based visualizations seem to be more precise to determine the extend of tumor spread and vascular involvement. Thus 3D- CT based visualizations representing the advantage of a single non-invasive examination of biliary tumors may complement conventional diagnostic tools and may improve treatment planning.

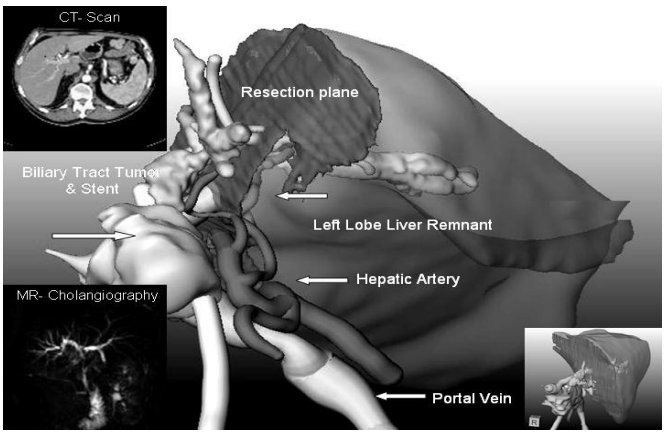

Figure 1. Computerized 3D viszualisation of a hilar biliary duct tumor, adjactend vascular sturctures the virtual oncological resection plane. Corresponding CT- scan und MR-cholangiography.

Living Donor Liver Transplantation: 3D- imaging studies were performed in 13 consecutive candidates evaluated for adult-to-adult living donor liver transplantation. Appropriate computerized 3D-visualizations of the arterial anatomy succeeded in 11/ 13 (84%) candidates. In the anatomy and the branching of the portal-, the hepatic veins could be visualized in all (13/13; 100%); clarification of the biliary tract anatomy succeeded in all of the 7 (7/7,100%) patients studied. Courses and branching points of the hepatic arteries, veins, bile ducts in relation to the intended splitting line could be displayed in a multidirectional view and in arbitrary combinations. Hepatic artery variants were detected in 5/13 (38.5%) patients. Display of the crucial segment IV artery succeeded in 11/13 (84.6%) patients. Both variants of the portal vein anatomy (n=2; 15.4%) were related to a trifurcation with early branching to the right liver lobe. Anatomic variants of hepatic vein ramification were observed in 6/13 (46.8%) patients. Computerized 3D-CT cholangiographic visualization provided precise mapping of the caliber, branching points, course and the relation to associated vascular structures. The course of the common and the hepatic bile ducts up to the to the 3rd order branches was clearly displayed. Variant bile duct anatomy with insulated drainage of the liver segment V into the cystic duct was detected in 1/7 patients. Adverse reactions related to the iodine content of biliary contrast agent used were absent in the observed patient set. In summary, our data indicate that 3D-CT based visualization facilitates diagnostic work-up with high accuracy. Multiple examinations especially with regard to invasive diagnostics may be avoided in future.

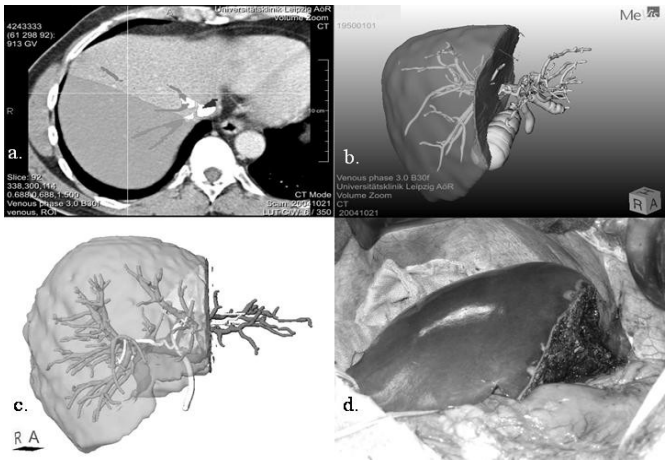

Figure 2. Computerized simulation of the living donor remnant after virtual dissection of the left lobe lateral segment graft for a pediatric recipient (a-c). Intraoperative view after removal of the left lobe lateral segment graft (d).

IV. Conclusion

Research on computer assisted surgery has expanded rapidly allowing application for clinical procedures on routine basis. Two fields of engineering technologies are required to realize computer assisted surgery in visceral organs: (1) a surgical simulation system to realize planning according to the condition and anatomical feature of the patient, (2) an image fusion system which is applicable for visceral organ surgery and acts as an apperatus for image guided surgery.

Application of computerized segmentation techniques on digital data derived from computer tomography facilitate 3D- geometrical and structural organ analyses. Computer simulations permit multiple viewing perspectives. Interactive insertion of resection lines ensures preoperative identification of "saftey margins" and "areas of risk" in oncological patients and in living related liver donors. Results achieved are accurate and robust. Data may be used as a "virtual road map" during surgery. Because of the inability of precise intraoperative registration image-fusion during visceral surgery render computer assisted surgery presently impossible. Physiologic organ shifting and soft organ composition with deformation during surgical manipulation are obstacles. The actual manual operating process is guided by fusion of visual and tactile

information. For image assistance and representation during surgery developments in the design of modern operating rooms with the operational availability of computer technologies offer an interim solution. Consequently computerized 3D- visualizations can be transferred and displayed on flat screen monitors near to the surgical field.

Pancreatic Tumors: Imaging of pancreatic tumors shows considerable progress. About 35% of pancreatic tumors are demonstrated to be resectable with curative intent[4]. Assessment of resectability, in most cases remains unclear until surgical exploration. Conventional diagnostics often fail to provide accurate assessment of regional tumor infiltration. Further limitation is the inability to depict small hepatic and peritoneal metastases. Neither conventional CT techniques, nor MRI and angiography can rule out these problems. From the surgical point of view 3 issues have to be addressed clearly by the preoperative staging of pancreatic tumors: (1.) local resectability; (2.) lymph node metastases and (3.) distant metastases. Accuracy for these determinants can be established by CT- and MRI in 71% and 70% respectively [5]. Computerized CT based 3D- visualization techniques may allow improved precision of staging pancreatic tumors that includes: (1.) interactive visualization of the pancreatic tumor (2.) tumor size (3.) display of the vascular anatomy; i.e. variants which are essential for surgical dissection and lymphadenectomy; (4.) tumor involvement of vessels; (5.) preoperative computerized resection planning in order to ensure adequate "safety margins". The potential of CT based 3D-visualizations to detect metastatic lymph nodes remains to be shown. In summary, our preliminary experience suggests that 3D-modeling of CT data should be included in staging of pancreatic tumors in selected cases. Small peritoneal and hepatic metastases can not be visualized sufficiently. In such suspected cases laparoscopy is useful and favorable compared to diagnostic laparotomy.

Biliary- Tract Tumors: Evaluation of biliary- tract tumors is an assessment of resectability, since resection is the only effective therapy. Resectability ranges between 10- 50% with 5-year survival rates of 20%. Preoperative staging must assess 4 critical issues: (1.) extend of tumor within the biliary tree, (2.) vascular invasion, (3.) hepatic lobar atrophy, (4.) metastatic disease [6]. Cholangiography (ERC) demonstrates the location of the tumor and the ductal extent of the disease. The procedure however carries a considerable risk. In addition MRC provides information regarding patency of hiliar vascular structures, presence of nodal and distant metastases and of lobar atrophy. There are a few limtations including cost, availability, operator dependence, patient tolerance and representation. In biliary- tract tumors experience with 3D- CT based visualizations is rare. CT based 3D- visualization meet above mentioned requirements. Quality and accuracy in the accomplished investigations in our opinion was superior to MRC. CT based 3D-visualizations provide improved tumor localization and a virtual view of vascular structures within the liver hilum and the hepatoduodenal ligament (Fig.1). 3D- mapping probably allows meticulous tumor dissection and effective protection of crucial vascular structures. In hilar bile duct tumors preoperative visualization of the course, the caliber and the branching of bile ducts will facilitate intraoperative identification for bilidigestive reconstruction. Application of the procedure is limited due to possible side effects of the contrast medium [7]. The procedure however may be indicated in cases of non-obstructed bile ducts (living donor liver candidates) or in patients with contraindications to PTC and MRC.

Living Donor Liver Transplantation: 3D- CT based visualizations achieved increasing acceptance in the work-up of in living donor liver transplantation especially in the asian world. The complex anatomy of the liver with high incidence of vascular variants reinforce the necessity for accurate preoperative vascular imaging. Up to one-third of potential donors may not be eligible for the procedure because of unsuitable vascular anatomy [8]. CT based 3D- visualization is non- invasive. Our data presented suggest that the method has achieved a robust standard. The procedure gives essential and detailed information about: variants of the hepatic artery, origin of the artery to segment IV, anatomy of portal and hepatic veins, variants of the biliary- tract. In addition the liver volume can be calculated. In our opinion the results of 3D-visualization of CT- based cholangiograms were as good as those by ERC and seem to be superior than MRC- scans. According to our experience preoperative interactive simulation of the splitting line in the donor liver is of major value because it identifies "areas at risk". These are margins along the splitting line of potential arterial devascularization or venous congestion (Fig.2). In conclusion, 3D- CT based visualization seems to be a valuable tool in order to perform this surgical procedure with high accuracy and to minimize potential risks to the donor and the graft.

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