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Ewa Pietka
Jacek Kawa
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# Information Technologies in Biomedicine, Volume 4

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Ewa Pietka · Jacek Kawa
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# Preface

In clinical application we deal with problems that have to be solved in a fast and objective way. However, human observation is influenced by internal (coming form the observer) as well as external (often independent from the observer) impacts. The objectivity of classification is restricted by the receptivity of human senses which are influenced by the experiences or level of training, psychological conditions (tiredness, haste, etc.), as well as external conditions (lighting, destructive noise, etc.) A failure in perception questions the entire recognition process. The recognition process itself, influenced also by the above mentioned conditions, may cause a slowdown and/or lead to a false diagnosis.

New computerized approaches to various problems have become critically important in healthcare. Computer assisted diagnosis has been extended towards a support of the clinical treatment. Mathematical information analysis, computer applications together with medical equipment and instruments have become standard tools underpinning the current rapid progress with developing Computational Intelligence. We are witnessing a radical change as technologies have been integrated into systems that address the core of medicine, including patient care in ambulatory and in-patient setting, disease prevention, health promotion, rehabilitation and home care. A computerized support in the analysis of patient information and implementation of a computer aided diagnosis and treatment systems, increases the objectivity of the analysis and speeds up the response to pathological changes.

This book aims to present a variety of state-of-the-art information technology and its applications to the networked environment to allow robust computerized approaches to be introduced throughout the healthcare enterprise. Image and signal analysis are the traditional parts that deal with the problem of data processing, recognition and classification. Bioinformatics has become a dynamically developed field of computer assisted biological data analysis. Patients' safety and shortening of the rehabilitation time requires a more rapid development of minimally invasive surgery supported by image navigation techniques. Home care, remote rehabilitation assistance, safety of the elderly require new areas to be explored in telemedicine and telegeriatrics.

This book set is a continuation of a book series. This set contains two volumes. *Information Technologies in Biomedicine, Volume 3* discusses Image analysis techniques and their applications in healthcare, as well as some Bioinformatics issues. *Information Technologies in Biomedicine, Volume 4* consists of six parts including Computer Aided Surgery, Telemedicine, Telegeriatrics,

We would like to express our gratitude to the authors who contributed their original research papers as well as the reviewers for their valuable comments.

Ewa Pietka

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# Part I

# Computer Aided Surgery

# Laparoscopic Liver Surgery

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**Abstract.** A survey of various laparoscopic liver surgery procedures is presented. First, depending on the tumor location, three patient positioning are discussed. Then, the resection procedures of benign and malignant lesions are presented. Pre- and intersurgical imaging techniques including 3D imaging and ultrasound procedures are often employed. Finally, the survival rate reported by various authors after nearly 15 years of experiences concludes the study.

**Keywords:** liver laparoscopy, liver surgery.

## 1 Introduction

There has been enormous growth of minimally invasive surgery since the first laparoscopic cholecystectomy. Commonly accepted laparoscopic procedures have now come to include bariatric and anti reflux procedures, distal pancreatectomy, splenectomy, hernia repair and colon resection. The earliest reports of laparoscopic liver surgery were limited to wedge resections for staging or isolated metastase [25]. Laparoscopic liver resection finally started to gain serious widespread attention after publication of Cherqui's initial thirty patient experience [10]. Since that time, the field has seen explosive growth, with over many cases now described in the world literature [29]. Despite its widespread acceptance, laparoscopic liver resection remains a daunting technical challenge suited to a relatively small number of centers that have taken the time and effort to develop concurrent expertise in both open hepatic surgery and laparoscopy. Once these hurdles are overcome; however, laparoscopic liver resection is a safe and highly effective procedure offering numerus patient benefits.

### 1.1 Benign Tumors

Benign liver tumors represent a diagnostic and therapeutic challenge. Traditionally, a highly conservative approach to benign hepatic tumors has been favored, owing to the historically high morbidity and mortality associated with open liver surgery. As operative and anesthetic techniques have improved, these hurdles have come down. Despite the increased safety of hepatic surgery, the indications for resection of benign hepatic tumors have changed little: symptomatic lesions,

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asymptomatic lesions at high risk of rupture or malignant degeneration, and inability to exclude malignancy nonoperatively. Because of concerns over oncologic adequacy, benign lesions represent the ideal starting point for a laparoscopic liver surgery program. Despite the attractiveness of minimally invasive surgery; however, surgeons should be cautioned that the ability to perform a laparoscopic resection should not change the indications for operation.

## 1.2 Hemangioma

Hemangioma represents the most common benign liver tumor, accounting for 5-20% of liver lesions [7]. These tumors typically occur in females in the third through fifth decades. Symptoms typically do not occur until the tumors grow relatively large (>5cm), and typically consist of abdominal pain resulting from stretching of Glisson's capsule. There have been reports of spontaneous, traumatic, or iatrogenic rupture. There is no potential for malignant degeneration with hepatic hemangioma. Hemangiomas demonstrate a typical pattern of enhancement on triple phase contrast enhanced CT. The lesion appears as a well circumscribed hypodense mass with peripheral enhancement in the arterial phase that will progress toward the center of the lesion. This pattern is typically known as centripetal enhancement. Sensitivity of triple phase CT has been reported from 75-85% with specificity of 75-100% [37]. Even better results have been reported with the use of magnetic resonance imaging, with reported sensitivity and specificity of up to 95% and 100%, respectively [35]. Because of the highly vascular nature of these tumors, percutaneous biopsy of suspected hemangiomas is contraindicated. As there is no malignant potential, symptomatic disease is the only generally accepted indication for surgical resection of hemangiomas. It should again be stressed that the availability of laparoscopy should not extend the indications for operation to asymptomatic patients. If pain is the indication for surgery, a thorough diagnostic workup is imperative to rule out other sources before attributing the symptoms to the hemangioma. The indication for surgery is more clear cut for large ruptured hemangioma, with patients often presenting in shock. Because of the dire consequences of rupture of large hemangioma, some surgeons would advocate the prophylactic resection of large lesions in patients with high risk occupations in areas remote from medical care. This opinion is controversial and should not be broadly applied.

## 1.3 Focal Nodular Hyperplasia

Focal nodular hyperplasia (FNH) is generally thought to arise as a hyperplastic proliferation of cells arising from an arterial malformation. This malformation may be congenital in nature such as telangiectasia or arteriovenous malformation, or may result from vascular injury [30,38]. The polyclonal nature of these lesions has significant impact on the radiographic evaluation of FNH, as it is the only common benign lesion that appears hot on Technetium sulfur colloid scan. This is from increased uptake of tracer in Kuppfer cells present within the lesion. FNH is typically an incidentally discovered lesion in women of late child bearing age, presenting most commonly from age 30 to 50. The female to male ratio has been reported at up to 8:1 [28]. Unlike hepatocellular adenoma, FNH is not influenced by oral contraceptive use. The radiographic appearance of focal nodular hyperplasia is typically diagnostic. On triple phase computed tomography, FNH will show transient enhancement on arterial phase. On delayed imaging, the characteristic central scar then becomes hyperenhancing. This central scar represents the vascular pedicle of the lesion and is pathognomonic. The most common diagnostic difficulty is distinguishing FNH from adenoma, which may best be achieved by contrast enhanced MRI. In this setting, sensitivity and specificity can reach 97% and 100%, respectively [36]. FNH is asymptomatic in upwards of 80% of cases [7]. In very rare instances, these lesions may present with hemorrhage. There are no reported cases of malignant degeneration of FNH thus far. Because of this, there is no indication for resection of asymptomatic lesions, regardless of the size and number of lesions. Surgical resection is reserved for the rare cases in which the lesion is symptomatic or when the diagnosis is not secure.

### 1.4 Hepatic Adenoma

Hepatic adenoma is a less common benign hepatic neoplasm, arising most commonly in women of child bearing age. There is a strong association between development of these lesions and oral contraceptive or androgenic steroid use. While the incidence is 0.1 per year per 100,000 patients who don't use oral contraceptives, there is a marked increase to up to 4 per 100,000 oral contraceptive users [30]. The introduction of modern contraceptives with lower estrogen content has led to a decrease in incidence [34]. Less common risk factors for the development of hepatocellular adenoma include glycogen storage disease type I and type III [27]. Though typically presenting as solitary lesions, adenoma may also be present as multiple lesions. Hepatic adenomas can grow quite large, with tumors of up to 30cm reported in the literature. Ultrasonography typically lacks diagnostic utility for adenomas, which can range from hypo to hyper-echoic. Reported sensitivity of ultrasound is only around 30% [14]. The CT appearance is that of a discrete, hypodense lesion showing enhancement on arterial phase followed by washout on later images. T1 weighted MRI will show a hypoto hyperintense lesion, while T2 images will show a lesion that is more isointense. Patients with hepatocellular adenoma are more likely to present with symptomatic disease than those with FNH. Epigastric or right upper quadrant pain is present in 25-50% of patients [7]. Spontaneous hemorrhage is also relatively common with these lesions, occurring in over 20% of patients. These complications are more likely to occur in men and with lesions greater than 5cm in diameter [15]. Perhaps the most feared complication of hepatocellular adenoma is malignant degeneration. The risk has been reported in the range of 8-10% [15,30]. Although 5cm is the generally accepted size at which malignant degeneration becomes a concern, cases have been reported in lesions as small as 4cm [27]. There is also a greater risk of malignant degeneration in males and in patients with the metabolic syndrome. Malignancy within adenomas is typically discovered only after surgical resection. In the case of small adenomas in the setting of oral contraceptive use, a period of observation following the cessation of contraception is warranted. Surgical resection in this setting is then reserved for lesions which fail to regress or continue to grow after stopping the offending medication. As with other benign lesions, symptomatology that can clearly be attributed to the adenoma is also an indication for surgical resection. The presence of multiple adenomas, or adenomatosis, is an arbitrary distinction rather than a distinct pathologic subtype, thus indications for resection are the same as for solitary adenoma. Because of the well defined risk of malignant degeneration, there are also cases where resection of asymptomatic lesions is warranted. Generally accepted criteria include adenomas greater than 5cm in size, or any adenoma in a male, regardless of size [15].

## 2 Laparoscopic Liver Benign Lesions Surgery

There are three commonly used patient positions employed in laparoscopic liver resection: supine, lateral decubitus, and the so-called French position in which the patient is supine with the legs in stirrups and the surgeon is positioned between the patient's legs. The appropriate position is determined based on the location of the tumor, and the surgical technique to be employed. The French position has the advantage of allowing the surgeon to operate with both hands while assistants can retract from either side of the table. The supine position is best employed when approaching lesions on the left lobe or right anterior sector of the liver. The lateral decubitus position places the patient recumbent on their left side at an angle of sixty degrees. This position allows access to the posterior segments of the right liver, as the left side down positioning prevents the liver from falling dependently into the operative field. When a hand port is to be employed, it is generally placed in the right upper quadrant as dictated by the position of the tumor being resected. A number of parenchymal transection techniques have been described in the literature, with none of them showing clear superiority over the others. Which technique is ultimately chosen thus becomes dependent upon the individual surgeon's comfort level with a given technique. Here I describe two of the more common strategies: electrosurgical dissection and stapler hepatectomy.

Electrosurgical transection techniques rely upon the surgeon's ability to operate two devices simultaneously. The surgeon should use a device such as the Harmonic Scalpel or Enseal in the dominant hand. This device is used to incise Glisson's capsule and for the majority of parenchymal transection. The device should not be fully introduced into the parenchyma to prevent tearing of large vessels. When aktive bleeding is encountered, it is immediately controlled with bipolar cautery forceps which are held in the surgeon's other hand. Larger vessels require the use of laparoscopic clips. Our group has favored the use of stapler hepatectomy. This technique provides the advantage of more rapid parenchymal transection, without the need for prior control of individual hepatic vessels. The first centimeter of parenchyma is relatively devoid of major vessels, and is incised with electrosurgical devices as described above. The dissection then proceeds using the thin blade of the stapler as a dissector. Care must be taken to avoid inadvertent manipulation of the stapler during firing, which can lead to tearing of major vessels and subsequent hemorrhage. The use of hand assistance is helpful in stabilizing the stapler to prevent such complications. We have preferred the use of a 25 mm vascular staple load for parenchymal transection. When intraoperative hemorrhage is encountered, the presence of a hand in the abdomen is highly beneficial in allowing digital control of bleeding vessels prior to attaining definitive hemostasis. Should conversion be necessary during a pure laparoscopic procedure, it should initially be to a hand assist method rather than to full laparotomy. In all cases, conversion should not be viewed as a failure or complication, but rather as a measure of prudent judgment [6].

## 3 Laparoscopic Resection of Liver Malignant Lesions

After becoming comfortable with resection of benign lesions, the logical progression in the development of a laparoscopic liver program is the resection of malignant lesions. These lesions require an increased degree of skill on the part of the surgeons in order to attain adequate margins and maintain oncologic adequacy. The presence of cirrhosis in the setting of HCC or steatohepatitis following neoadjuvant chemotherapy for colorectal metastasis make proper patient selection and timing of operation critical. The consideration of adjunctive techniques such as transarterial chemoemboliztion for preoperative downstaging also becomes important.

Here, we will discuss laparoscopic management of the two most common malignant hepatic tumors: colorectal metastases and hepatocellular carcinoma. Colorectal metastases are the most common malignant hepatic tumor. Results following open resection of these lesions have been excellent, with 5 year survival rates exceeding 50% in many centers [18]. Such outcomes have set a high standard by which laparoscopic resection must be measured. The adoption of laparoscopy to this field has been hindered by concerns of tumor seeding at port sates and the possibility of missing extrahepatic lesions by inadequate inspection of the peritoneal cavity [19,21]. These hurdles have slowly been brought down, and laparoscopic resection is now a standard part of the therapeutic arsenal for hepatic malignancy. Patient selection criteria for laparoscopic resection of colorectal metastases are similar to those applied for open resection. Initial evaluation requires precise definition of tumor anatomy and exclusion of extrahepatic disease. We favor triple phase CT as the initial radiographic evaluation. When combined with digital arterial reconstruction, evaluation of aberrant vascular anatomy, which can be present in nearly half of all patients, is afforded. Evaluation of baseline liver function is performed with evaluation of bilirubin, INR, and albumin. A thorough history and physical exam is necessary to assess general fitness for major abdominal surgery. Tumor resectability is defined by the SSAT as an expected negative margin resection with preservation of at least 2 contiguous hepatic segments with adequate inflow, outflow, and biliary drainage and a future liver remnant of more than 20% for normal parenchyma [9]. The most critical factor to producing positive outcomes is the attainment of negative operative margins (R0 resection). Facility with laparoscopic intraoperative ultrasound is a must for surgeons approaching malignant liver lesions, allowing for precise definition of tumor anatomy and planning of resection planes. As long as negative microscopic margine are obtained, there does not appear to be a minimum necessary margin width [32].

The approach to synchronous disease has received considerable attention, as it will be present in up to 25% of patients with colorectal liver metastases [26]. There are three possible surgical strategies in this setting: the classic approach of colorectal resection followed by hepatectomy, a simultaneous resection of colorectal and hepatic disease, and a reverse strategy of metastasectomy followed by primary tumor resection. The drawback of the classic strategy is the delay in metastasectomy while patients receive adjuvant therapy. The combined strategy eliminates this delay, at the cost of greater surgical insult with possibly higher morbidity. Brouquet's analysis of all three strategies found similar morbidity, mortality, and survival across groups, showing that no approach is clearly superior for all patients [5].

With increasing worldwide experience of laparoscopic resection of colorectal metastases, the oncologic integrity of laparoscopy compared with open techniques has been shown to be comparable. Nguyen's review of the world literature found only one case of port site recurrence, which occurred in a case of metastatic renal cell carcinoma that ruptured prior to resection [29]. Castaing's comparison of 60 patients undergoing laparoscopic resection and 60 patients undergoing open resection provided the first evidence of long term efficacy of laparoscopic resection for colorectal metastases. Five year survival in the laparoscopic group in this series was 62%, which was comparable to the 56% five year survival in the open group. There was no difference in width of resection margins between groups, while the laparoscopic group included a greater percentage of patients undergoing combined hepatic and colorectal resection [8]. Such results confirm that laparoscopic resection is a safe and effective alternative to open surgery for hepatic colorectal metastases.

Hepatocellular carcinoma (HCC) is the sixth most common malignancy and the third most common cause of cancer death worldwide [31]. In the United States, where chronic hepatitis C infection is the main risk factor, there has been an increase in the incidence of HCC over the past several decades [16]. Most patients present with relatively advanced disease, making curative treatment such as resection and liver transplantation applicable in only 30-40% of patients. One of the major limiting factors in preventing resectability is impaired hepatic fiction. Thus, appropriate patient selection becomes paramount in achieving successful outcomes. Because of these limitations, the role of laparoscopic liver resection has remained more limited than for other disease states. Much of the patient selection process for resection of HCC centers around assessment of the underlying liver parenchyma. The Child-Pugh classification system provides a rough framework from which to base the selection process. In generally, Child A patients are able to tolerate limited forms of resection, while Child B and C patients are typically referred for more palliative procedures such as systemic therapy or transarterial chemoembolization. In the West, assessment is directed at determining the presence of significant portal hypertension. Generally, patients with hepatic-venous pressure gradient of less than 10, esophageal varices of no greater than grade 1, and platelet counts of over 100,000 are considered acceptable risk. In addition, bilirubin levels must be normal. A common technique in Eastern centers is the assessment of indocyanine green clearance rate (ICG). This technique involves the injection of an organic dye which is then measured in the peripheral blood after a 15 minute interval. Clearance of the dye is used as a surrogate for hepatic metabolic function. ICG retention of no more than 10-20% is considered to be acceptable. Using this technique in 1056 consecutive patients with normal bilirubin and no ascites, Imamura has been able to achieve hepatic resection with zero operative mortality [20].

Advances in imaging technology have lead to the increasing use of systemic liver volumetry as a preoperative risk assessment tool. A future liver remnant to standard liver volume ratio of greater than 20% is considered safe in patients with healthy liver parenchyma, while ratios of 30-40% are considered necessary for patients with compensated cirrhosis. An insufficient future liver remnant may be addressed with the use of adjunctive techniques such as portal vein embolization, which will be discussed in greater detail in the section on resection in cirrhotics.

Tumor related factors that preclude surgical resection include extrahepatic disease and invasion of the main portal vein, vena cava, and common hepatic artery. Multinodular disease that can't be resected with an adequate future liver remnant is also a relative contraindication to resection, although there is a role for resection of the dominant lesion with radiofrequency ablation of the remaining disease in highly selected cases. Although size alone is not a criteria for resectability, there is a practical limit to the size of lesion that can be safely approached laparoscopically. The recent international position statement for laparoscopic liver surgery recommends limitation of the laparoscopic approach to tumors <5cm in diameter for all but the most experienced of centers [6].

Unlike the case of hepatic colorectal metastases, there does appear to be a benefit to wider surgical margins in patients with HCC. For patients with solitary HCC lacking vascular invasion, a margin of at least 2cm has proven beneficial in a randomized controlled trial setting. Furthermore, the tendency of HCC to spread via the portal venous system favors the use of planned anatomic resection in patients with adequate hepatic reserve. The inability to perform anatomic resection should not be considered a contraindication, however, as more limited resection as been shown to be beneficial in the setting of cirrhosis [33]. Despite the limitations imposed by the greater difficulties in technical resection and patient selection, laparoscopic resection has proven to be a safe and effective alternative to open surgery in appropriately selected patients. Lai has demonstrated 5 year survival of 50%, with disease free survival of 36%, while Dagher has shown 5 year overall and disease free survival of 64.9% and 32.2%, respectively

[12,23]. Others have shown laparoscopic resection to be associated with lower morbidity and postoperative ascites compared to open resection [4]. Although hepatocellular carcinoma in the setting of cirrhosis represents the most difficult of diseases to approach via laparoscopy, these results show that the technique is safe and effective when performed in centers that have acquired the appropriate experience.

## 4 Laparoscopic Treatment of Patients with Cirrhotic Liver

As noted above, the cirrhotic patient represents a unique challenge to the laparoscopic liver surgeon. The possibility of postoperative liver failure resulting from inadequate remnant liver function is a dreaded complication to be avoided at all costs. One technique that can potentially prevent this problem is the use of preoperative portal vein embolization (PVE). The effectiveness of PVE is based on the remarkable regenerative capacity of the liver. The technique involves occlusion of the tumor bearing segments of the liver, which induces hypertrophy in the remaining hepatic segments. Generally, reimaging 6 weeks after PVE is performed to assess the adequacy of hypertrophy to provide an adequate future liver remnant. Failure to achieve adequate hypertrophy indicates a severely diseased liver that is not amenable to resection.

A meta-analysis of PVE has been found that the procedure is safe and able to induce adequate hypertrophy to reduce post resection liver failure in a considerable proportion of patients [2]. Preoperative PVE is currently recommended in cirrhotic patients with predicted future liver remnant of less than 40%. For centers using ICG retention, values of 10-19% with a FLR of 40-60% also represents an indication for portal vein embolization [33].

For cirrhotic patients able to undergo liver resection, laparoscopy provides a number of unique benefits. The smaller incisions cause less disruption of the abdominal wall collateral circulation. As complete evacuation of ascites is not necessary for a laparoscopic procedure, intraoperative fluid shifts are lessened. This contributes to the reduction in postoperative ascites seen with laparoscopy compared to open hepatectomy [13,17]. Another unique benefit is the reduced adhesion formation following laparoscopic surgery. For patients undergoing resection of HCC, salvage transplantation remains an important option for recurrences that are within the Milan criteria. Laurent found that liver transplants following laparoscopic compared to open resection were performed in less time, with less blood loss and transfusion requirement [24]. Similarly, Belli has found repeat hepatectomy following initial laparoscopic resection to be faster and safer, with less blood loss and risk of visceral injury [3].

The recent international consensus conference on laparoscopic liver surgery has developed guidelines for the establishment and credentialing of a laparoscopic liver surgery program [6]. Prior to embarking upon beginning a program in laparoscopic liver surgery, it is necessary to acquire experience with both advanced laparoscopy and open hepatic surgery. These requirements have made the widespread adoption of laparoscopic liver surgery appropriately slow. As advanced laparoscopy becomes an increasingly important part of general surgery training programs, these prerequisites will become less of a hurdle, with the expected more rapid acceptance of laparoscopic liver surgery. After establishing the necessary expertise in laparoscopy and open hepatic surgery, the ideal starting point is small, benign lesions in the periphery of the liver. Extensive use of hand assistance is also critical in reducing the learning curve. Koffron has described the hybrid technique, in which mobilization of the liver is performed laparoscopically, and parenchymal transection is then performed in an open fashion through the hand port incision [22]. He has termed this approach "laparoscopic liver surgery for everyone", and we agree that this approach represents an ideal starting point for a laparoscopic liver program.

Once comfortable with performing more limited resections, the next step in development is the performance of major, anatomic resections. In this setting, the left lateral segmentectomy is the ideal starting point. Although much attention is given to the parenchymal transection phase, it should be noted that the greatest risk for vascular injury and subsequent conversion to an open procedure is actually during the mobilization phase. The most commonly injured vessel in this setting is the phrenic vein, which must be carefully identified and avoided. Conversion, as we have emphasized previously, should not be viewed as a failure or complication. Instead, the decision to convert to an open or hand assisted procedure rather than continue with a potentially unsafe situation laparoscopically is a mark of good surgical judgment.

Experience with resection of lesions located in the peripheral segments of the liver provides a foundation of skills, including mobilization, transection, hemostasis, and laparoscopic ultrasound. Once this fundamental skill set has been developed thoroughly, the surgeon is then able to proceed to more difficult lesions. At this point, malignant and/or large lesions located in the right and posterior segments of the liver can then be approached in the culmination of programmatic development. We have found that facility with minor resections can be achieved in 30 to 50 cases. More difficult resections such as formal lobectomy and right posterior resection require an additional 60 to 80 cases to master. Thus, the road to development of a laparoscopic liver resection program is long and often arduous, but is highly rewarding to both the surgeon and the patient when properly travelled.

## 5 Robotic Surgery

Robotic surgery is a new and promising technique. Numerous authors believe it as revolutionary as laparoscopy or thoracoscopy [1]. Multiple instruments, very useful in some cases, have been introduced. They are still being developed and sometimes far from perfection. Very many centers worldwide perform robotic procedures and publish their results. The cost of the procedure versus the benefit for the patient are the most often mentioned issues. Radical prostatectomy and some cardiac surgical procedures appear to be the most frequent indications.

Robotic-assisted surgery is a new method requiring conscientious analysis of the previous results. The method is still being developed and it is difficult to state which indications are beneficial for patients. Surgeons must try to avoid marketing operations behind some of the indications of companies producing robotic instrumentation.

Advantages of robotic surgery surely include benefits of mini-invasive procedures (laparo- and thoracoscopy): small incisions, less painful sensation, better recovery and fewer complications connected with it, reduced blood loss, higher precision of the surgeon. It is also economically beneficial due to shorter hospital stay, reduced consumption of analgesics, decreased number of transfusions.

On the other hand, the high cost of a robotic procedure appears to be the biggest, current problem in the world. Although, richer countries may afford wider utilization of such techniques (the USA), scrupulous economic analysis has to be done: costs versus benefits for the patient versus health care system in the particular country [11].

## 6 Conclusion

Nearly 15 years after first being described, laparoscopic liver resection has been gradually gaining acceptance in a number of centers worldwide. As the necessary skills in advanced laparoscopy and hepatic surgery become more widespread, we anticipate that the further adoption of laparoscopic liver resection will increase more rapidly. The maturation of long term series have proven the oncologic adequacy of the laparoscopic approach in a variety of settings. With the development of a greater number of surgeons who are proficient in laparoscopic liver surgery, many more patients will benefit from decreased blood loss, less postoperative pain, and shorter lengths of stay. From being a novel procedure practiced in only a handful of centers worldwide, laparoscopic liver resection is now established as a safe and effective technique in the therapeutic decision tree for patients with surgical disease of the liver. We believe that this acceptance will continue to grow to the point that the laparoscopic approach will, as has been seen with colon resection, eventually be adopted as the standard of care in appropriately selected patients.

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# Assistance in Destroying Focal Lesions in the Liver Using Image Navigation

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**Abstract.** Article presents methodology of computer aided destroying focal liver lesions using imaging navigation system. Methodology allows generation of personalized anatomical model of patient's liver based on CAT screening with contract media of abdominal cavity, registration of edited anatomical model relative to real patient's position on operation block, presentation of surgical tools position during treatment on the liver's anatomical model and non-direct monitoring of ablation process of lesions. Liver anatomy model comprises organ's and focal lesions' surface and central lines of vascular structures in liver. Generation of personalized patient's model has been verified based on anonymized abdominal cavity CAT with contrast media screening cases. The registration methodology has been evaluated on imaging data and patient from the Second Department of Clinical Radiology and the Chair and Department of General, Transplant and Liver Surgery at the Medical University of Warsaw after acceptance of the ethics committee of the Medical University of Warsaw.

**Keywords:** ablation of liver tumours, image navigation, personalized model of liver's anatomy, computer aided diagnostics and therapy.

## 1 Introduction

Primary and metastatic liver tumours make an significant challenge for contemporary medicine. Among available techniques of destroying focal liver lesions there are resection techniques,which are the most effective and ablation techniques applied in cases where resection techniques can't be used [1]. Additional difficulty in case of destroying focal liver lesions using ablation techniques is big organ's movability during breathing, which is an effect of the fact that liver is adjacent to diaph. Organ displacements can reach a few centimetres, which causes target point to displace [2,3]. Imaging navigation systems aids treatments performance through presentation of treatment run on a spatial patient's anatomy model [4,5]. Model's task is to show the most important anatomical structures from the performed treatment point of view, target point and surgical tools positions visualization on anatomical model. Nowadays in clinical practice imaging

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navigation systems are commonly used for treatments using stiff human body skeleton's elements as referral points, for example: skull's bones, spinal cord's elements etc. Imaging navigation of parenchymal organs is more challenging due to lack of fixed referral points. The aim of this work is the presentation of imaging navigation system methodology supporting destruction of non-resectional focal lesions in the liver using ablation techniques.

## 2 Material and Methods

After literature studies, simulation and pilot studies methodology of aiding of destroying focal liver lesions focused on ablation techniques were proposed, especially electrical ablation with radio frequencies were considered. Methodology consists of a few stages:

- Preparation of personalized patient's anatomy model.
- Treatment planning.
- Registration of patient's position during treatment in comparison to pre-treatment patient's anatomy model.
- Operation field visualization during treatment and ablation process monitoring.

### 2.1 Preparation of Personalized Patient's Anatomy Model

Creation of personalized anatomical liver's model is based on patient's abdominal cavity CT examinations with contrast. Based on CAT images the following are found: liver's surface, vascular structures and volumes of focal liver lesions. For liver volume segmentation semi-automatic method proposed by Juszczyk is applied [6]. The method requires to indicate a single point within the spleen and one point inside the liver. The points indicated by the user are treated as a beginning of the rolling vector by which finding a common area in liver and spleen in two-dimensional cross-section is performed. After assigning the labels of object on the current cross-section, the shape of the image is transferred to the adjacent images. Stopping condition is to find the layer without the labeling of the object. Once you find the volume of the spleen, remove it from the initial volume and the result volume is the correct volume of the liver.

Vascular structure segmentation applies the modification of vascular Frangi filter [7], based on the analysis of the eigenvalues of the Hessian matrix. The method consists of two stages. At the first stage method determines the intensity characteristic of liver tissue, removes the structure of "hard" (e.g. high-density structures) and smoothes the image using anisotropic filtering. Then modified filter proposed by Rudzki is used [8], which is a modification of vascular Frangi filter, and introduces sigmoidal response functions of gaining a better sensitivity and higher immunity to noise.

The segmentation of lesions in the liver CT study raises a number of problems well-known and described in the literature [9] [10]. The changes, depending on the type, size, and stage of malignancy, are characterized by different levels

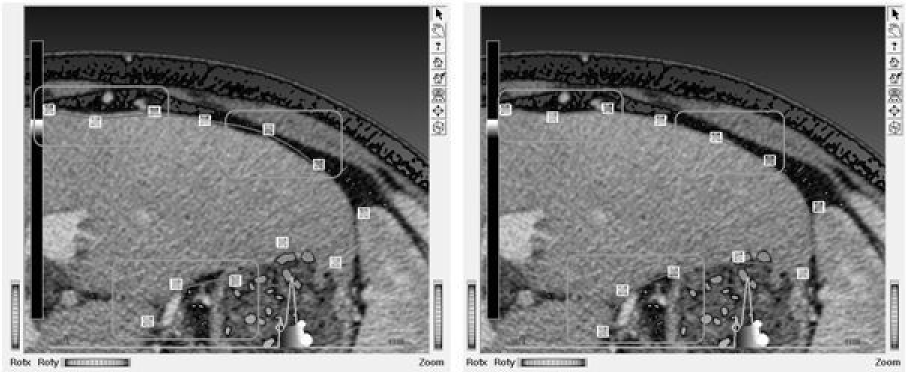


**Fig. 1.** Liver model evaluation: before correction - left, after correction - right

of intensity. Segmentation procedure of the growth area with adaptive criteria selection is applied, proposed by Badura [11]. Fuzzy expert system is used to monitore the shape, size and nature of the intensity of the tumor region.

Details on used segmentation methods were presented in the articles [8,6,11,12]. Building of personalized patient's model requires point inside liver parenchyma and one point for each focal lesion. Finding vascular structures does not require identifying specific points in liver's images, while applied algorithm uses the liver's mask obtained at the stage of segmentation. After indication of mentioned starting points personalized anatomical liver's model is generated automatically. Automatic results obtained in the stage of segmentation are processed to generate geometric models based on B-splines curves which makes it easier to use them at a later stage. After results receipt verified by a physician radiologist is planned, by evaluating the results of segmentation presented on the background of layered CT images the abdominal cavity. There exists possiblity to manually correct segmentation results by editing the splines' control points representing contours of segmented structures (Fig. 1). Vascular structures are presented in the form of central lines using smooth splines, they are also manually correctable (Fig. 2).

It is possible to block control points in the selected plane. This option is useful for manual correction of liver's contour segmentation results, where cuts of obtained model are presented in corresponding plane. In case of control points relocation in space, which is the case when correction of control points of vascular structures has been done (Fig. 2), movement of control points in any direction is possible.

### 2.2 Treatment Planning

To plan treatment personalized anatomical patient's liver model, presented in previous point, is used. Author has proposed a method of presentation of anatomical liver's model in the way suitable for treatment's planning. Model's presentation using selected layered DICOM images (2D presentation of selected cut of the chosen volume in corresponding layered CT cut - Fig. 1) and presentation of the whole volume of abdominal cavity (volumetric imaging Fig. 3). Liver's outline and focal lesions are presented in the form of organ's surface cuts corresponding to specific DICOM images. Presentation of segmented structures on the background of layered images of abdominal cavity allows to assess resectability changes and select entry point on the patient's surface (Fig. 4), target point located inside segmented focal change (Fig. 3) and follow whether on the potential trajectory of surgical tool there are any organs which should be omitted during tools introduction. Selection of the point of entry is done by mouse on CT volume. Coordinates of indicated points are stored and used at a later stage of treatment.

### 2.3 Patient's Position Registration Relative to Pre-operation Anatomical Liver's Model

As registration process in the present case we understand explicit projection of position on the patient body to the corresponding position in the preoperative anatomical model built on the basis of layered CT images. Registration process takes place using markers placed on patient's abdominal cavity surface before CAT is performed. Markers placement is presented in Table 1 and Fig. 4. To perform registration it is necessary to determine position of the markers on CT images and the patient surface. Having a set of markers' coordinates in both coordinate systems Horn algorithm is used [13,14] in order to find stiff match between coordinate system of personalized anatomical liver's model and coordinate system related to real position of the patient on an operation block. Positioning of the various markers is found on CT images and stored in order to carry out calculations to find a rigid transform algorithm using Horn algorithm.

Stiff match between patient position and personalized anatomical model during treatment is not sufficient due to deformations of patient's body taking place which are effects of breathing movements and pressure of surgical tools. To take those things into consideration non-stiff registration is introduced which allows to take into the account local shape deformations. Non-stiff registration

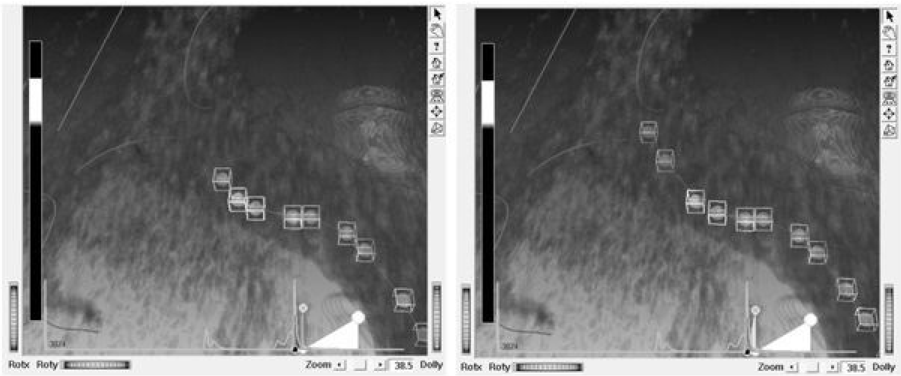


**Fig. 2.** Vessel skeleton evaluation: before correction - left, after correction - right

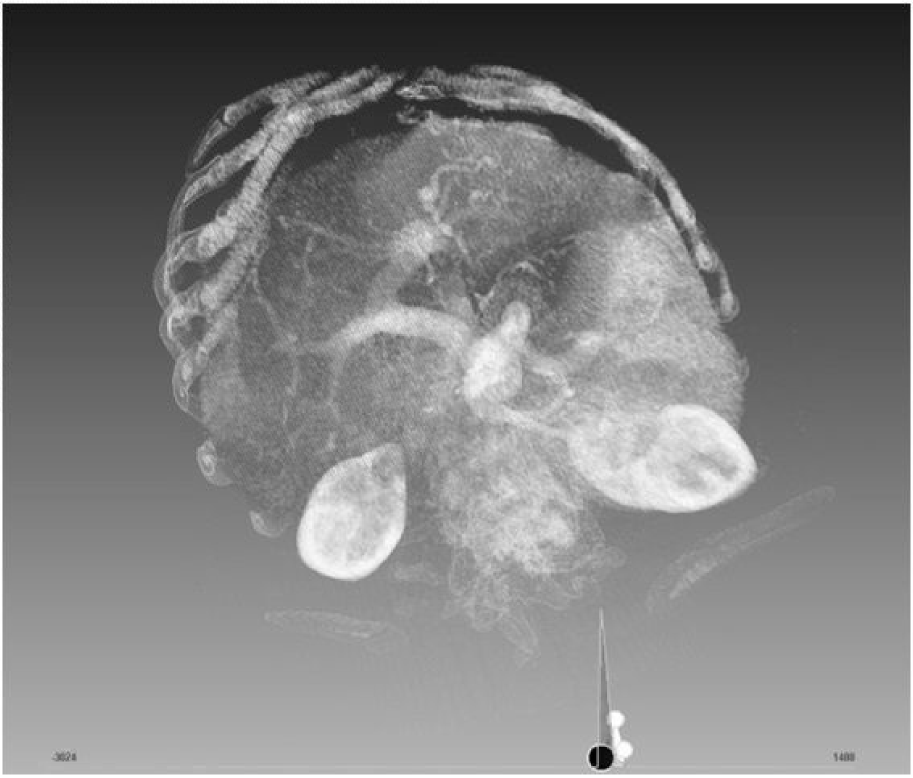

**Fig. 3.** Focal liver lesion - volumetric presentation

is based on so called deformation field, which is in turn based on a markers position interchanges, which are observed continuously during treatment. Based on deformation field correction of target point position is estimated. Deformation area allows to calculate target point position correction for various respiratory phases. More accurate definition of respiratory phase and the methodology for calculating deformation area and results obtained in various respiratory phases are presented in the paper [15], where obtained correction of deformation area was compared with the actual position of the target point, using as target point one of the markers, position of which was continuously tracked by position tracking system. In the paper averaged results obtained from 10 patients with any liver diseases from the Second Department of Clinical Radiology and the Chair and Department of General, Transplant and Liver Surgery at the Medical University of Warsaw, for various markers configuration in relation to target point were presented.

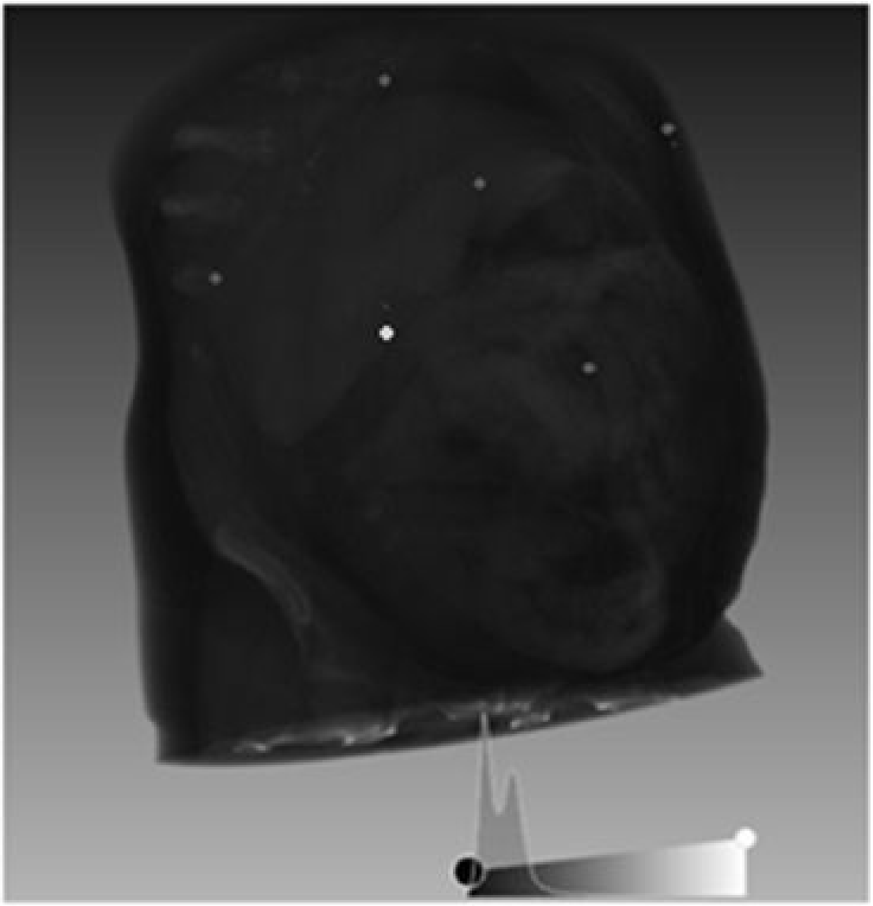

**Fig. 4.** Abdominal surface of the patient with markers

### 2.4 Operation Field Visualization During Treatment and Ablation Process Monitoring

In order to aid treatment performance graphical interface has been proposed which presents current position of surgical tools (in this ablation needle) on personalized anatomical patient's model. Current position of ablation needle is tracked by position tracking system NDI Polaris Vicra. Key element which is crucial for successful ablation treatment in starting phase is placement of ablation needle ending as close as possible to the proposed target point. For this purpose serves viewer interface (Fig. 5), which shows ending of ablation needle position relative to target point during needle introduction, and deviation of needle introduction direction relative to direction between entry and target points - found during treatment planning phase [16]. Located next to the

**Table 1.** Anatomical position of skin markers for manual registration

| Anatomical location | Grounds |
|---|---|
| Xiphoid process | Point fixed to bony structures in the midline of the body |
| Intersection of midclavicular line and right costal margin | Anatomical point fixed to bony structures |
| Intersection of anterior axillary line and right costal margin | Anatomical point fixed to bony structures |
| Intersection of midclavicular line and left costal margin | Anatomical point fixed to bony structures |
| Intersection of anterior axillary line and left costal margin | Anatomical point fixed to bony structures |
| First control point on the abdominal surface | Registration accuracy validation |

toolbar, indicates by its length the distance between ablation needle tip and target point. Located in the centre of the disc two points represent the ends of ablation needle onto a plane perpendicular to the direction the plane is aiming, which is visualized in a red-white plate.

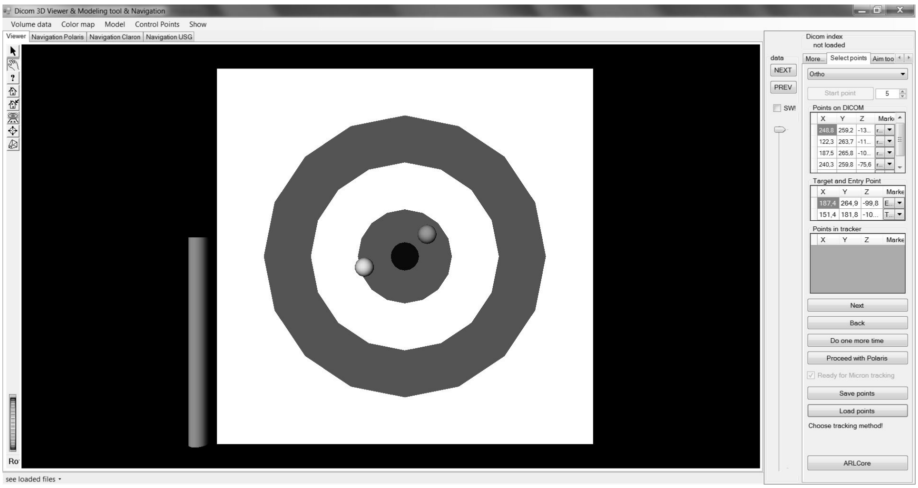


**Fig. 5.** Graphical user interface supported needle insertion

Second important element is to monitor tumour's ablation process. In order to do it bipolar system of electrical ablation with radio frequencies Celon produced by Olympus has been integrated. It allows for non-direct ablation process monitoring through tracking of electrical parameters: tissue resistance, momentary power and total energy delivered to the apparatus. Example of the process of animal liver tissue ablation is shown in Fig. 6. System automatically terminates the ablation process once it detects an increase in tissue resistance around ablation needle (Fig. 6 - end of lower graph).

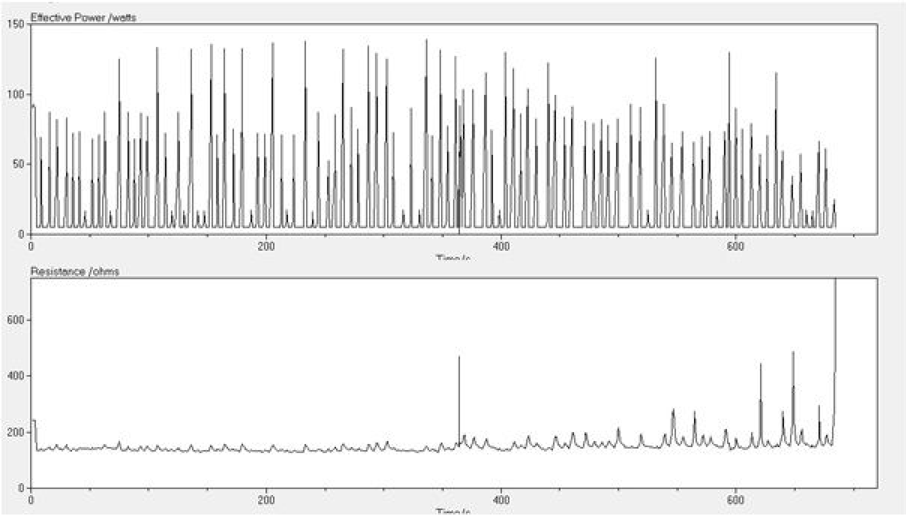


**Fig. 6.** Diagram of temporary power (up) and tissue resistance (bottom) during swine liver ablation from Olympus Celon device

## 3 Results and Conclusions

Proposed methodology for creation of personalized liver anatomical model verified on anonymized cases of abdominal cavity CT. In the proposed methodology automatically obtained segmentation results are submitted for verifications by radiologist and only then verified model serves in the next phase of planning of destroying focal lesions. Due to lack of ability to verify segmentation results directly for example in the case of vascular tree as a measure of segmentation results level of vascular structure branches has been proposed. Vascular tree segmentation has been performed successfully to third or fourth level of branches on average [8]. Results of registration were presented in previous article [15]. Two registration methods of abdominal preoperative CT and physical patient position in OR were presented and compared. This approach is being developed as a step to image guided percutaneous liver tumor ablation. The proposed equation of deformation is calculated in real time. Assuming regular breathing conducted by the respirator, recurrence of patient position and short time between CT study and procedure, the proposed solution could be used to synchronize the respiratory phase for which the static preoperative CT anatomical model was generated, which is one of the most challenging steps in RF ablation [15]. Conducted pilot studies confirmed possibility of application of proposed methodology for destroying focal liver lesions. Further studies direction is to fully integrate proposed methodology in the clinical environment and to verify correlation between external markers movement with internal organs displacement.

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# Image Navigation in Minimally Invasive Surgery

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**Abstract.** This study presents the development of an image navigation system dedicated to assist a miniinvasive abdominal surgery. First, the system overview is discussed. Then, a development of a mesh model of abdominal structure is presented. Next, a system calibration including the component as well as patient registration is described.The evaluation of the system has been performed separately for each component. The accuracy of calibration as well as patient registration is reported. This yields the robustnes evaluation of the overall system.

**Keywords:** Image navigation, visualization, calibration.

## 1 Introduction

The term of image navigation denotes a stereotactic surgical technique that uses preoperative CT or MRI data that match the corresponding surgical anatomy using three-dimensional coordinates to enhance intraoperative accuracy and anatomic orientation [1]. These systems are used in clinical tests since early 90's [2]. Due to the simplicity of anatomical landmarks registration onto the radiological data, neurosurgery [3,4] and orthopaedics [5] are the pioneering procedures. Moreover, location of anatomical structures corresponds to its appearance in the preoperatively acquired radiological data.

In this study an image navigation system employed in abdominal minimally invasive surgery is built. In these procedures insuflation and breath related organ motion require compensation. Some attempts have already been made to overcome these problems [6] and reconstruct the organ surface [7].

The main goal of this paper is to assess the accuracy of calibration and patient registration. The paper is organized as follows. Section 2 presents the system with the calibration procedure, patient registration, image preprocessing and display. Section 3 discusses the results. Section 4 concludes this phase of the study.

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## 2 System Overview

Image navigation system described in the paper is based on the Polaris Spectra (NDI Inc., Canada [8]) optical tracker and dedicated markers attached to various elements during the procedure. Polaris Tracker is widely used by research centres for surgery that implements the navigation imaging systems [8,9]. Two items tracked during the surgery are laparoscopic instruments and the operating table.

While tracking the surgical instruments is a standard procedure, the purpose of attaching the marker to the table needs some explanation. This is an indirect way to track the position of the operating field during the surgery. This permits the camera to be moved around the table during the procedure. Without tracking the operating table, the camera cannot be displaced.

### 2.1 Local Coordinate Systems

Each element of the navigation system is related to a coordinate system, local for each item. The most common coordinate systems and objects related to them are presented in Tab. 1.

**Table 1.** Local coordinate systems commonly used

| Element of the system | Referencing coordinate system |
|---|---|
| Tracker | „Global" coordinate system |
| Stylus | 1. Fixed polaris marker |
| | 2. Stylus tip coordinate system |
| Forceps | 1. Fixed polaris marker |
| | 2. Forceps tip coordinate system |
| Patient's body | Polaris marker fixed to the operating table |
| DICOM Image | DICOM coordinates |
| Organs' models | DICOM coordinates |

All transformations between coordinate systems are performed by isometric transformations (i. e. rigid body transformation) and are stored in the $4 \times 4$ transformation matrix. Rigid body transformation is an arbitrary composition of translation and rotation of the coordinate frame.

Let $P^X$ be coordinates of point $P$ in the frame $X$, and $P^Y$ is coordinates of point $P$ in the frame $Y$. Let $M_Y^X$ be a transformation matrix from coordinate frame $Y$ to $X$, then

$$P^X = M_Y^X \cdot P^Y. \quad (1)$$

Transforming repeatedly one coordinate system into another is considered as a consecutive multiplying of the transformation matrices. For example, if coordinates of $P$ are given in $Z$ and matrices $M_Y^X$ and $M_Z^Y$ are known, new coordinates of $P$ in $X$ are found by:

$$P^X = M_Y^X \cdot M_Z^Y \cdot P^Z. \quad (2)$$

Note that

$$M_Y^X = \left(M_X^Y\right)^{-1}. \tag{3}$$

In order to connect all coordinate systems, transformation matrices have to be found. These matrices can be either variable or invariant. The first group denotes actual positions of Polaris markers, while invariant transformations have to be calculated at the beginning of the operation, i. e. surgical tool's pivot calibration, patient registration.

To determine the transformation between any two coordinate systems, one has to multiply all transformation matrices, according to the equation (2). Each transformation between two coordinate systems has a certain inaccuracy, which refers to the translation as well as the rotation. The scheme of transformations is shown in Fig. 1.

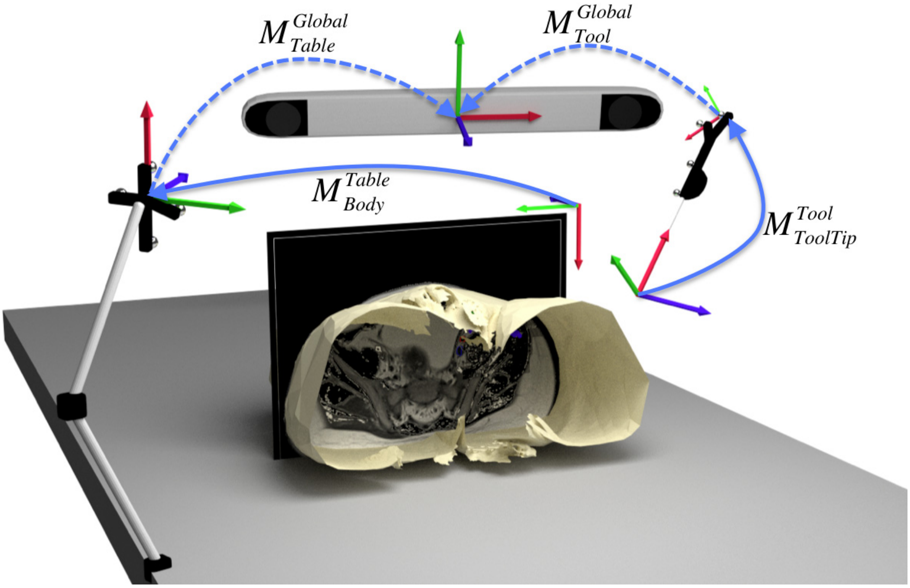


**Fig. 1.** Transformations between different coordinate systems; solid lines reflect invariant transformations and dashed lines reflect variable transformations

### 2.2 Tool Tip Calibration

Calibration of the tool tip (laparoscopic forceps and stylus) is a process of determining the invariant transformation between the coordinate system associated with the tool tip and the Polaris marker attached to this tool. The calibration involves fixation of the tip and rotation of the device around the pivot point (Fig. 2). The positions of the marker recorded in the global coordinate system are then used to determine the transformation matrix $M_{ToolTip}^{Tool}$. Once the matrix is known, the coordinates of the tip are given on-line.

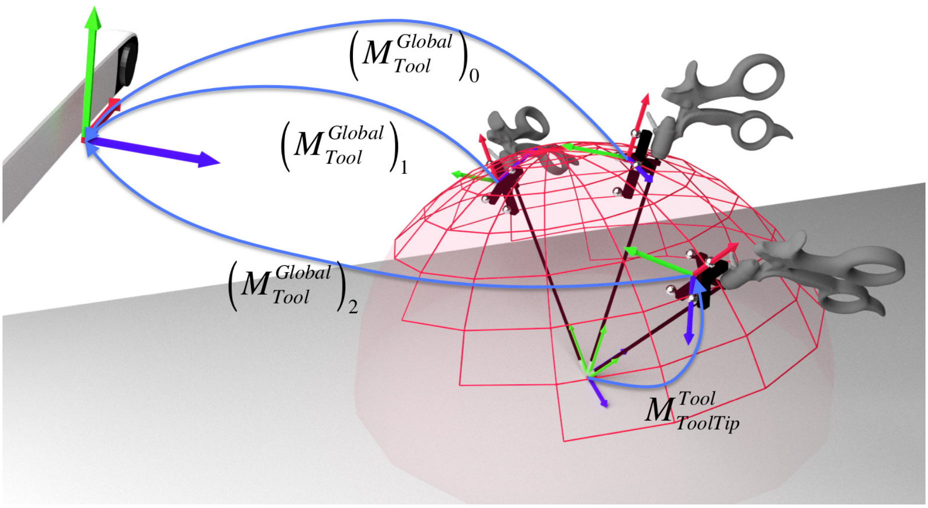


**Fig. 2.** Surgical tool calibration consists of recording multiple positions of the marker on tool $\left(M^{Global}_{Tool}\right)_i$ in order to compute the transformation matrix $M^{Tool}_{ToolTip}$

Calculating matrix $M^{Tool}_{ToolTip}$ on the basis of multiple registered matrices $\left(M^{Global}_{Tool}\right)_i$ is the optimization problem of overdetermined system of linear equations [10,11]. To solve it, the LSQR method [12] has been implemented.

### 2.3 Radiological Data Preprocessing

Most of the approaches to medical image segmentation are studies on automatic segmentation algorithms [13,14], although semi-automatic methods are also common [15,16]. However, none of them has yet succeeded in creating universal software able to facilitate the segmentation of all anatomical organs. The difficulty of the problem lies mainly in the variety of shapes, locations, and homogeneity of the segmented structures. The complexity increases when pathological structures of blurred edges are extracted.

Results of the segmentation are stored as binary DICOM masks or directly as contours for each of the slice of the image. Regardless of the format, they are in the same coordinate system as the original data. In order to convert segmented structures from raster to a mesh grid, a program based on VTK implementation of the marching cubes [17] method has been developed. In the case of manual contours delinated in OsiriX[1], built-in tools have been used. Such models require additional processing, which is performed using the program

[1] OsiriX website: `http://www.osirix-viewer.com/`

Blender[2]. The goal of processing is mainly to simplify the model (by remeshing), to remove unnecessary elements such as free vertices and edges, and to transform the position to the coordinate system compatible with 3DSlicer[3].

Both the radiological images and the models created on the basis of them are oriented in the LPS (Left-Posterior-Superior) coordinate system. This means that X, Y and Z axes increase towards left, posterior and superior direction, respectively. On the other hand, Slicer uses the RAS (Right-Anterior-Superior) coordinate system, so that the objects loaded into it have to be flipped along the X and Y axes. These models are loaded directly into the Slicer scene. The workflow is shown in Fig. 3.

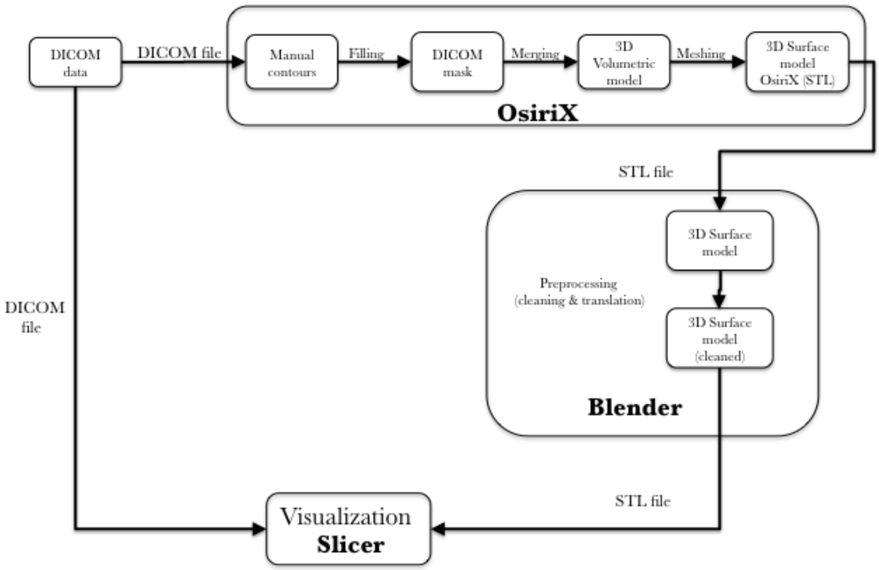


**Fig. 3.** Data preprocessing workflow

### 2.4 Patient's Registration

Patient's registration is a process of transforming points located on patent's skin and corresponding voxels into one coordinate system. At least three non-collinear points are needed to determine the transformation between the coordinate systems. Typically, the points do not overlap and determined transformation minimizes the residual sum of squares (RSS). Patient's registration is computed with Horn's algorithm of absolute orientation [18] also known as "Landmark-based registration algorithm". Measurements are performed before to determine,

[2] Blender website: `http://www.blender.org/`
[3] 3DSlicer website: `http://www.slicer.org/`

which points on the patient's body are the best to carry out the registration, i. e. their residuals are the smallest.

During the calibration only anatomical landmark points are used (no artificial landmarks have been attached to the patient's body). Although artificial landmarks could increase the registration accuracy [19], their sterility required during the surgery may not be guaranteed.

The landmark points on patient's body are located in the image and their position in DICOM coordinate system should be taken before the surgery.

### 2.5 Visualization

The program 3DSlicer is used to display the virtual scene during the operation. MRI or CT slices in several planes and three-dimensional virtual scene are shown simultaneously (Fig. 4). Two-dimensional views change dynamically when forceps moves showing the slice of the current tool location.

Current markers position are being sent to the Slicer in the form of transformation matrices by OpenIGTLink protocol. The communication is provided by a PLUS library [20].

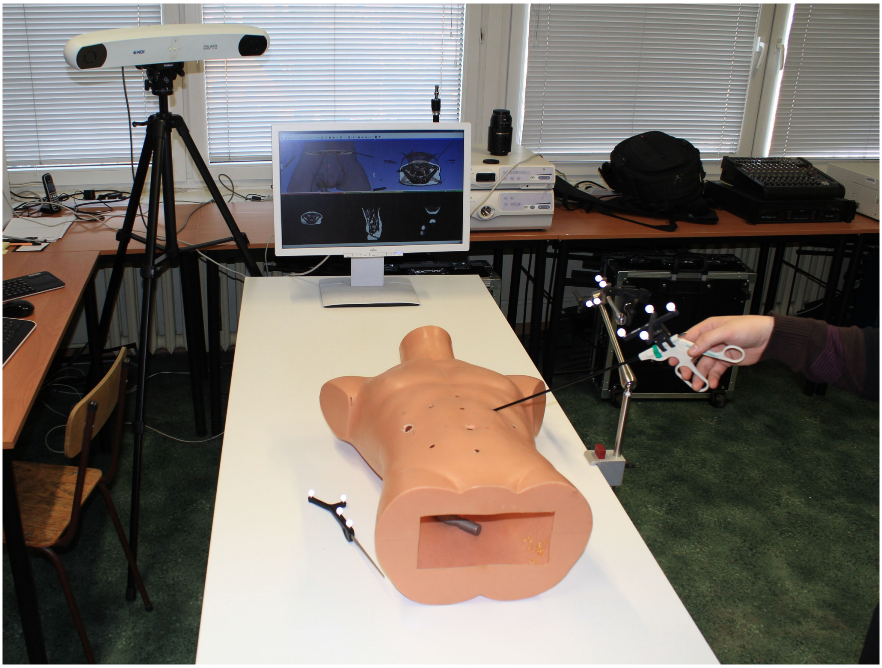

**Fig. 4.** Image navigation system and the visualization of models

Coronal and sagittal views of the three-dimensional patient model are displayed simultaneously (Fig. 4). If necessary, the perspective can be easily changed (e.g. to the lateral or oblique view). Two-dimensional scans are also displayed.

## 3 Results

Two settings have been employed for the system evaluation. The first set-up measures the calibration accuracy, the second one assesses the exactness of the patient registration. The accuracy of the Polaris tracking system is at the range of 0.2 mm.

In order to measure the performance of the calibration procedure, 30 experiments have been repeated. Each of them recorded 200 positions of the tool tip. The results (Tab. 2) indicate an influence of the tool length. The longer the distance between the marker and the pivot point, the more the inaccuracy of rotation influences the total error.

**Table 2.** Calibration accuracy of stylus and forceps tips

| Radius length [mm] | Mean error [mm] | Std deviation [mm] |
|---|---|---|
| 160.3 | 0.21 | 0.07 |
| 357.3 | 0.52 | 0.14 |

Patient registration accuracy is based on nine landmarks points on the surface of the abdomen. The following points have been chosen:

- Xiphoid process of sternum (XP)
- A point in the middle of costal arch right and left (CAR, CAL)
- Anterior superior iliac spine right and left (ASISR, ASISL)
- Greater trochanter of right and left femur (GTR, GTL)
- Umbilicus (U)
- Pubic symphysis (PS)

They have been recorded just before the CT abdomen or pelvis examination. Thus, these landmarks are acquired and marked on the CT scan. Due to the obesity of the patient, the presence of an ostomy bag on the left part of abdominal wall, bandages after recent surgeries of abdomen and pelvis, or a thick layer of clothes, the points located over trochanters and pubic symphysis are sometimes missed (Fig. 5)

After the conversion of all points, a Fiducial Registration Error (FRE) has been found [21]. It is defined as a distance between the current position of a point in the original coordinate system and its corresponding position after the conversion of the second coordinate system. The results are shown in Tab. 3.

The overall system accuracy is defined as a distance between the tool tip that points the target and its location displayed on the 3D patient model. Our first approach to the accuracy analysis yields the results of 24.17 mm (Tab. 4).

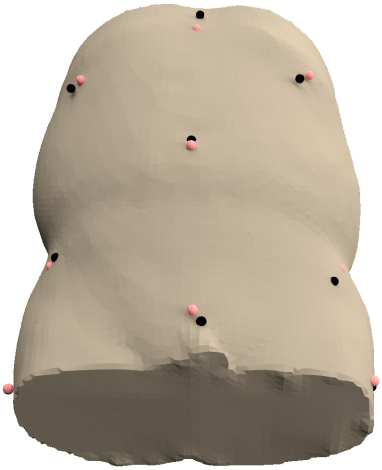

**Fig. 5.** Position of landmarks on the model in DICOM (light) and transformed Polaris (dark) coordinate system

**Table 3.** FRE values of anatomical landmark points at 9 studies [mm]

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | mean |
|---|---|---|---|---|---|---|---|---|---|---|
| XP | 36.52 | 15.77 | 30.11 | 45.78 | 8.12 | 20.46 | 15.38 | 21.26 | 30.22 | 24.85 |
| CAR | 26.81 | 26.52 | 44.81 | 15.96 | 22.50 | 30.85 | 10.35 | 26.37 | 14.53 | 24.30 |
| CAL | 26.70 | 22.43 | 54.65 | 23.76 | 14.84 | 41.03 | 7.03 | 34.09 | 19.46 | 27.11 |
| ASISR | 6.57 | 35.67 | 27.35 | 11.26 | 10.69 | 22.76 | 28.11 | 28.45 | 11.16 | 20.22 |
| ASISL | 13.10 | 23.44 | 23.30 | 26.89 | 24.10 | 36.18 | 29.63 | 36.47 | 29.39 | 26.94 |
| GTR | – | 9.08 | 23.74 | – | 28.76 | 23.98 | 16.07 | – | 18.11 | 19.96 |
| GTL | – | 35.72 | 34.30 | – | 31.01 | 27.38 | 22.58 | – | 12.29 | 27.21 |
| U | 17.34 | 43.54 | 16.41 | 15.27 | 15.06 | 11.01 | – | 36.20 | 11.74 | 20.82 |
| PS | – | 40.07 | 20.60 | 15.95 | 20.06 | 7.07 | – | – | 14.05 | 19.63 |

**Table 4.** Partial and total errors of the system [mm]

| Erorr | Value [mm] |
|---|---|
| Marker track error | 0.2 |
| Tool tip calibration error | 0.52 |
| Fiducial registration error | 23.45 |
| Total | 24.17 |

## 4 Summary

In this paper a methodology of navigation in minimally invasive surgery has been shown. Procedure of tools calibration and patient registration is discussed. Development of the patient abdomed model has been described. Visualization system available in the operating room is proposed. The overall accuracy of the entire procedure is described and the error is less than 24.17 [mm].

Patient registration process can be performed in the operating room, and the system is ready for testing in clinical settings. Presented system is dedicated to organs fixed to the abdominal wall and insuflation process does not cause their motion.

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