Minimally invasive digital technology: A new edge tool for the diagnosis and treatment of hepatolithiasis

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Prof. Chihua Fang is a doctor of medicine, professor of the second grade, an archiater, a doctoral supervisor, and a postdoctoral tutor. He is the director of The First Department of Hepatobiliary Surgery of Zhujiang Hospital Affiliated to Southern Medical University, of the Clinical Engineering and Technological Research Center of Digital Medicine of Guangdong Province, and of the Clinical Digital Medical Research Center of Southern Medical University. He is the director-designate member of the Chinese Society of Digital Medicine, the executive director of China Graphics Society, and a committee member of group of bile duct surgery of Chinese Medical Association. He serves as an associate editor or editorial board member for 15 academic journals including Digital Medicine, Chinese Journal of Minimally Invasive Surgery, Chinese Journal of Digestive Surgery, Chinese Journal of Surgery, and Chinese Journal of Practical Surgery. He pioneered to apply digital medical technology in the diagnosis and treatment of diseases involving the hepatopancreatobiliary (HPB) system, especially in HBP surgery. He has more than 10 scientific projects supported by the Key Project of Natural Science Foundation of China and National 863 Plan of China of the 11th and 12th 5-year plans. He has won more than 10 prizes, among which are the Tech Awards of Guangdong province (one first and two second prizes), the Award of Chinese Medical Doctor, and the Tech Awards of Ding Ying of Guangdong Province. He is an outstanding individual in medical field of China, a model worker of Guangdong Province, and a distinguished teacher of Guangdong high school. He has won the third-class merits for four times. He was the torch bearer of the 16th Guangzhou Asian Games and cultivated 126 postgraduates. He has spent 35 years in research and practice in HPB surgery. His main achievements include as follows: (1) He and his team have developed a medical image three-dimensional visualization system (MI-3DVS) and already obtained the China Food and Drug Administration certification with their own intellectual property right. Its function and performance have reached or surpassed that of the domestic and overseas congeneric products of its kind. It has filled in the blanks of this area in China and won the Innovation Achievement Prize of Chinese Industry-University-Research Cooperation. (2) He is the first one to present the concept of minimally invasive digital surgery and establish a 3D diagnosis and treatment platform for hepatolithiasis. (3) He pioneered to adopt 3D visualization technology to assist the treatment of pancreatic tumor, perform this type of surgery, and evaluate the resectability. The study results were published in Pancreatology and Pancreas. (4) He successfully applied individualized virtual surgery simulation system to make surgical plan of complicated hepatectomy and choose a reasonable operation method. It can greatly improve resectability and safety. He led his team to apply domestic initial liver 3D printing technology to assist in complicated hepatectomy in patients with rare variation of hepatic artery and portal vein. (5) He is the first to apply 3D printing technology combined with molecular imaging technique to treat complicated diseases in HPB surgery, define boundary and make early diagnosis of small/micro hepatocellular carcinoma, and perform precise surgical navigation.

THE CONCEPT OF MINIMALLY INVASIVE DIGITAL TECHNOLOGY AND ITS ADVANTAGE IN BILIARY SURGERY

In 1987, the world’s first laparoscopic cholecystectomy was successfully completed. It was a milestone in the history of general surgery and inspired a wave of minimally invasive surgery. Currently, in the minimal invasion era of biliary surgery, there is a general trend that the application of minimally invasive surgery should be extended to take place of complicated open operation. The surgical techniques, for the moment, are mature. Instead of the surgical techniques themselves, the “software” supporting the surgery is the bottleneck to limit its development. With the rapid development of information technology, digital medicine, as a frontier discipline, has come
forth. It is an interdiscipline involving clinical medicine, biology, computer science, mechanical engineering, and informatics. It is widely applied to all aspects of the medical field today, even including preclinical medicine, hospital management, and hospital construction. The minimally invasive digital technology rises with the continuous development of digital medicine and minimally invasive surgery in the proper time and under proper conditions. It combines some digital medical technologies—3D reconstruction, 3D visualized analysis, visible simulation surgery, and 3D printing—and applies them to clinical practices to provide support for educating the medical staff and performing surgical training, preoperative planning, intraoperative navigation, and postoperative evaluation. All these are done to accomplish the goal of mini-invasive surgery.

Great progress has already been made in the techniques of medical imageology and image processing. It takes on some new changes in the research on modern anatomy. Image inspection methods, such as B ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI), have improved the research methods of human organ and organizational structure and made them more diverse. It makes the anatomic study based on living body possible without using the traditional research mode which mainly includes morphological description. The cross-sectional imaging derived from CT/MRI could provide some detailed information about the anatomy of bile duct systems and its appendant 3D reconstruction workstation could make 3D image model base on a sagittal/coronal view. Therefore, the longitudinal stereoscopic shape of bile duct systems could be visually displayed. It is very difficult to show the intrahepatic vascular and bile duct systems clearly at the same time; therefore, it limits its ability to make a comprehensive diagnosis. In other words, the above image reconstruction does not use 3D reconstruction in a real sense. When dealing with the complicated pathologic changes in bile duct systems from the patients with hepatolithiasis, it is difficult to make a precise diagnosis and evaluate the state of illness. Thus, it may lead to poor therapeutic effects.

The digital 3D reconstruction and virtual reality technology have already been applied in medicine, and the visual anatomical structure of living human has been a hot spot of current study. The 3D reconstruction of visual liver by the computer image processing technology is performed, and 3D representations in moving images are adopted to replace the traditional 2D images. These 3D images can show the spatial structure and adjacency relationship among the intrahepatic vasculatures of the patients with hepatolithiasis from all dimensions and multi-angles. They can provide more significant imaging information for disease diagnosis and therapeutic schedule, accelerating the development of biliary surgery.

**THE VALUE OF APPLYING MINIMALLY INVASIVE DIGITAL TECHNOLOGY IN THE DIAGNOSIS AND TREATMENT OF HEPATOLITHIASIS**

The pathogenesis of hepatolithiasis is complicated and the treatment is difficult, especially when it is accompanied by portal hypertension, atrophy-hypertrophy complex of the liver, and portal translocation. The calculuses are distributed widely in the intrahepatic bile duct systems and the shape of vasculatures may have variations. Patients with hepatolithiasis may have multiple complicated stenosis of bile duct sometimes and a lack of effective imaging examination before operation may result in inaccurate diagnosis and therefore incorrect surgical indications, leading to high residual and recurrence rates. As a result, the residual and recurrence rates are 20～50% and patients need to receive multiple operations. Currently, the therapeutic principles of hepatolithiasis are removing lesions, taking out of stones completely, corrective strictures, effective drainage, and preventing and curing the recurrence. Hepatectomy was considered the most effective therapy for hepatolithiasis. In recent years, the application of some minimally invasive technology with 3D laparoscope, percutaneous transhepatic cholangioscopic lithotripsy (PTCSL), and choledochoscope has also achieved satisfactory therapeutic effects. No matter what approaches we choose, acquainting with the stone distribution, the shape, expansion, and stenosis of bile duct systems and the shape of the other three intrahepatic vascular systems are essential for disease assessment and decision of surgical plan. The 3D visualization technology plays an important role in diagnosing and treating hepatobiliary and pancreatic diseases, especially hepatolithiasis. The clinical effect is good and the value of its application is mainly reflected in these following aspects.

**Precise diagnosis before the operation**

*Getting high-quality computed tomography imaging data of hepatolithiasis*

Due to the obvious personal differences among patients with intrahepatic stones, it is difficult to get high-quality CT imaging data through the traditional CT scan methods (delayed scanning), and it could directly affect the image models of 3D reconstruction for hepatolithiasis.
We have gained a good effect using the optimized text injection method—observing the intrahepatic intravascular enhancement by the single-level dynamic CT scan through preinjection of small dose CT contrast agent. Therefore, we could clearly observe the hepatic artery, portal vein, hepatic vein, and their branches. In comparison to the traditional CT scanning image with a slice thickness ranging from 5 to 10 mm which may miss the key information of bile duct disease, we could acquire high-quality CT image data containing a lot of disease information. We used these submillimeter CT images of bile duct systems to complete the data segmentation and 3D reconstruction.

We input the image data into MI-3DVS which has a self-owned intellectual property right and constructed an individualized 3D image model of hepatolithiasis successfully. The 3D image models of hepatolithiasis have a strong stereo sense and vivid colors. The intrahepatic vascular systems are clearly displayed and are consistent with the physical truth of patients themselves. Doctors can use personal computer to shrink, magnify, split, combine, hyalinize, and measure the image models to analyze the state of illness and complete the 3D visualization display of the whole intrahepatic vasculatures and peripheral vessels. Therefore, we could make an accurate diagnosis of the distribution of stones, the degree of biliary duct stenosis, and the pathologic change of the liver.

At the same time, we can recognize the types of hepatic vessels and get familiar with the blood vessels. We can also perform the liver segmentation based on 3D visualization technology; therefore, the distribution of calculus and the degree of bile duct disease can be precisely identified. We can distinctly recognize that the definite segments are affected by the stones and distinguish the degrees of coronary artery stenosis. Together with pathological implications of the liver, we can make a scientific and reasonable typing diagnosis. It is important to comprehensively understand the disease and make a surgical planning.

**Individualized surgical planning**

When knowing very well of the distribution of stones and the disease extent of bile duct systems and abdominal organs, surgeons can perform virtual operations by a virtual surgery simulation system. By comparatively analyzing different surgical plans, they can eventually choose the best scheme to optimize surgical process. Therefore, elaborate perioperative management could be easily obtained, making the precise liver surgery possible.

We can check on the feasibility of hepatectomy using indocyanine green 15, child-Pugh liver function grade, and marking index for end-stage liver disease. The residual liver volume proportion is widely used in routine clinical work. This 3D software can be used to perform virtual hepatectomy to get the residual liver volume proportion which is essential to evaluate the viability of surgery. Volume calculation of the liver segments together with other liver function indexes could be used to make a comprehensive evaluation for surgical security. For hepatolithiasis, the 3D visualized analysis of visceral organs, intrahepatic stones, and vasculatures is completed when the 3D reconstruction is finished. In addition to the benefits mentioned, intraoperative precise operations are able to be guided by these image models to guarantee enough residual liver volume and decrease operative trauma. All of them are done to achieve the aim of using minimally invasive digital technology to treat hepatolithiasis, to implement the strategy of removing lesions, taking out of stones completely, corrective strictures, effective drainage, and maximizing residual liver volume.

**3D visualization plus pattern to treat hepatolithiasis and lower the residual and recurrence rates**

In recent years, as tremendous progress has been made in the endoscopic techniques, diagnosis and treatment of hepatolithiasis are moving toward precision and minitrauma. There are several therapeutic methods for hepatolithiasis including open/laparoscopic regular/irregular hepatectomy, transhepatic cholangiolithotomy, choledochojejunostomy, PTCSL, and liver transplantation. The optimal therapeutic schedule for hepatolithiasis is to remove lesions, namely the regular hepatectomy. Preoperative virtual hepatectomy based on 3D visualization analysis can point to the distribution of stones and bile duct lesions. When performing the virtual surgery, we can observe the vascular structure of hepatic cutting surface and calculate the residual liver volume by choosing different surgical planes. These will help to evaluate the feasibility and safety and determine the final surgical plan. Therefore, the surgeons could avoid vice damage, reduce blindness, shorten the operative time to a certain degree, and better short-term and long-term prognosis can be achieved.

We can observe the intrahepatic vascular systems at the same time through the 3D technology, and the guidance value for regular hepatectomy is quite obvious. (1) Defining the accurate boundary range of liver segment. It is very important to handle some difficult situations such as hypertrophy-atrophy syndrome, hepatic portal transposition, and significantly morphological
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change of liver after hepatectomy and to highlight the advantages of 3D technology. (2) Evaluating the residual liver volume. (3) Ensuring the blood supply and biliary drainage to be unobstructed which is crucial for the residual liver. By analyzing the 3D image model and evaluating the virtual surgery, surgeons could make sure that the residual liver has enough volume to maintain vital movement prepensely. Regular hepatectomy can beat the target of removing lesions, taking out of stones completely and corrective strictures, but there are risks of hepatic insufficiency after operation and superabundant resecting of normal liver parenchyma. Sometimes, we need to strike a balance between beneficial effect and surgical safety to treat some patients who cannot tolerate major hepatectomy. Whether they should receive complete accurate treatment or not is a controversial and difficult problem for patients with hepatolithiasis.

At present, liver resection is based on traditional imaging diagnosis methods, such as B ultrasound, CT, magnetic resonance choledangiopancreatography, endoscopic retrograde cholangiopancreatography, and percutaneous transhepatic cholangiography (PTC). These above image data are usually 2D and it is difficult to accurately position the intrahepatic calculus and find the possible variation of intrahepatic vascular systems. Therefore, it is difficult to develop a diagnosis and treatment strategy. Due to the specific pathological changes of patients with hepatolithiasis, the liver segment under the circumstances is different than the classical Couinaud segment. Precise liver segment could not be obtained by the traditional imaging examination. Therefore, performing the blind hepatectomy could not realize the therapeutic aim of hepatolithiasis, and the price would be sacrificing the normal liver parenchyma or inadequate blood supply to the residual liver or insufficient drainage. The liver segmentation using 3D technology is based on the principle that each single hepatic segment has blood supply by portal vein and hemal circumfluence by hepatic vein independently. Thus, the segmentation is precise and conforms to the principle of individualization. The precise liver resection technology is intent to provide patients with best prognosis, and the digital surgical platform is a powerful means to accomplish individualized medicine, consistent with therapeutic principle and the goal of minimal invasive operation. This principle also applies to the surgical treatment of hepatolithiasis.

In 1996, the resection of the left lateral lobe by laparoscope to treat the patients with hepatolithiasis was performed successfully for the first time. Since then, this technology has been widely applied. The application of laparoscopic operating system can bring many advantages such as high definition of operation field and distinct tissue layers. It is conducive to accurate operation and hemorrhage control during the surgery. Injury hemorrhage of gallbladder epithelium caused by extraction with conventional appliances can be avoided using the laparoscope in intraoperative period. The combined application of laparoscope and choledochoscope guided by 3D visualization technology has great advantages: (1) It can provide plenty of surgical choices and simplify some surgery; (2) Choledochoscope (especially rigid choledochoscope) can be used to directly observe the functional status of Oddi sphincter and avoid unnecessary choledochojejunostomy; (3) The 3D image model can play a role in indirect surgical navigation. Opting for this surgical procedure should be based on the following four conditions. First, there is no apparent fibrosis and atrophy in the diseased liver parenchyma. Second, drainage will be unobstructed after taking out of the stones. Third, the Oddi sphincter functions properly. Finally, pathological evidence shows that cancerization does not occur in the bile duct tissue. The application of the 3D visualization technology can confirm a diagnosis before the operation and acquire detailed information about intrahepatic stones for a precise diagnosis. When we are aware of the lesions and operative approaches, we can choose the laparoscope combined with the choledochoscope to perform the minimally invasive surgery. Using this method, the tremendous psychological and physical trauma brought by the traditional open surgery to the patients can be avoided.

The application of intraoperative choledochoscopy (including electronic choledochoscope and rigid choledochoscope) has a number of advantages: (1) Choledochoscopy can easily drift in and out of the bile duct, and the rigid choledochoscopy can even reach the grade 3/4 bile duct for studying, breaking, and removing the stones. (2) The adoption of lithotomy forceps or Cook basket alone may be difficult to take out of the intrahepatic calculus when dealing with some big stones and may cause laceration of biliary mucosa or bleeding. On such occasion, the assistance with pneumatic lithotripsy plus some heating and damage effect, the stones can be taken out easily. (3) Laparoscopic flush water spray system can exert a heavy pressure and help to pass stones safely and quickly. (4) The continuous vacuum aspiration can keep low/no pressure in the body, and it will greatly decrease the complication such as by preventing the bacteria from getting into blood circulation. The internal environment for recurrence of calculus can be eliminated, and the high relapse rate can be lowered with taking out of the stones completely. At the pathological level, it will be conducive to acquiring
in vivo biliary tissues to carry out the examination using a laparoscope, thus getting information rapidly and exactly to fully recognize other pathological changes.

PTSCL is a minimally invasive therapy for hepatolithiasis. The surgical procedure is generally divided into three stages. The first step is to perform percutaneous transhepatic biliary drainage (PTBD); the second one is to expand the sinus tract once a week after PTBD, and 2 weeks later, we need to expand the sinus tract to 16 F and use a cholecystoscope to take out of the stones. On account of little damage and high efficiency, this technology is gradually accepted by clinicians. Based on the 3D visualization precise diagnosis, the procedure of PTCSL can be optimized for successfully completing the precise minimally invasive surgery. The main difficulties of PTCSL are the uncertainty of punctured objective bile duct and the variability of intrahepatic vasculatures. As previously stated, the 3D visualization technology has already achieved precise diagnosis and ascertained a best operative approach through 3D simulation surgery to avoid blindness, increase efficiency of removing stone, avoid tearing bile duct and injuring biliary tract, without damaging abdominal vessels and organs. Patients receiving operation of biliary tract previously usually have abdominal scars and tight adhesion between liver and other visceral organs. In that case, the specific location of porta hepatis is crucial to reoperation. In the process of 3D visualized analysis, abdominal wall is considered to be a separate part and is shown together with liver, other visceral organ, and vascular systems. When we hyalinize the 3D model of abdominal wall, its relationship with porta hepatis can be shown clearly. It will provide key information for PTCSL to choose a reasonable puncture incision and pathway. The PTCSL guided by 3D visualization technology can optimize building of the operative channel, reducing frequency of expansion, and decreasing complications such as bile leakage and hemorrhage. It is a safe and efficient minimally invasive method to treat hepatolithiasis in short operative time. It has prominent effect and can provide a new way for the treatment of hepatolithiasis.

This 3D visualization plus pattern can obtain a good curative effect with an improved clearance rate and a decreased residual rate.

Tentative exploration of 3D printing technology in diagnosis and treatment of patients with hepatolithiasis
The 3D printing technology is widely used in orthopedics and its application in hepatobiliary surgery is very rare. We have already applied this technology in the treatment of complicated hepatocellular carcinoma and achieved good prognosis. Now, we have studied the value of this technology in the diagnosis and treatment of hepatolithiasis. The 3D printing model based on 3D visualization technology is in tune with original CT data. The model is real and shown in equal proportion. Surgeons can evaluate the spatial location relationship among calculus, bile duct, and vascular systems by observing the 3D liver model and then develop a solution. During the operation, 3D printing model can be brought into the operating room and compared with the real-time physical truth. It will provide intuitive navigation for the key steps in intraoperation and real-time guidance for separating vessels and eliminating stones. The 3D printing technology has realized the transition from 3D image model to veritable 3D material object. As it is a brand new diagnosis and treatment technique in digital medical surgery, future research is needed to study the value of its application.

With the development of 3D visualization technology, the era of precise surgery is coming. The seamless connection between 3D visualization and 3D printing technology will promote the development of 3D real-time navigation surgery. With 3D technology combining with different kinds of endoscopic equipment and minimally invasive surgical technique, this minimally invasive digital technology will play a significant role in the treatment of hepatolithiasis and telemedicine.

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