PO Box 2345, Beijing 100023, China
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RAPID COMMUNICATION

Clinical application of plasma shock wave lithotripsy in treating impacted stones in the bile duct system

Zhi Xu, Li-Xin Wang, Neng-Wei Zhang, Chun-Sheng Hou, Xiao-Feng Ling, Yao Xu, Xiao-Si Zhou

Zhi Xu, Li-Xin Wang, Neng-Wei Zhang, Chun-Sheng Hou, Xiao-Feng Ling, Xiao-Si Zhou, Department of Surgery, Third Hospital of Peking University, 49 North Garden Road, Haidian District, Beijing 100083, China
Yao Xu, Institute of Physics, Chinese Academy of Sciences, Beijing 100037, China
Correspondence to: Zhi Xu, Department of Surgery, Third Hospital of Peking University, 49 North Garden Road, Haidian District, Beijing 100083, China. xuzhi123456@sohu.com
Telephone: +86-10-62017691-2575 Fax: +86-10-62017700
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Abstract

AIM: To verify the safety and efficacy of plasma shock wave lithotripsy (PSWL) in fragmenting impacted stones in the bile duct system.

METHODS: From September 1988 to April 2005, 67 patients (26 men and 41 women) with impacted stones underwent various biliary operations with tube (or T-tube) drainage. Remnant and impacted stones in the bile duct system found by cholangiography after the operation were fragmented by PSWL and choledochofiberscopy. A total of 201 impacted stones were fragmented by PSWL setting the voltage at 2.5-3.5 kV, and the energy output at 2-3 J for each pulse of PSWL. Then the fragmented stones were extracted by choledochofiberscopy. The safety and efficacy of PSWL were observed during and after the procedure.

RESULTS: One hundred and ninety-nine of 201 impacted stones (99.0%) in the bile duct system were successfully fragmented using PSWL and extracted by choledochofiberscopy. The stone clearance rate for patients was 97% (65/67). Ten patients felt mild pain in the right upper quadrant of the abdomen, and could tolerate it well. Eleven patients had a small amount of bleeding from the mucosa of the bile duct. The bleeding was transient and stopped spontaneously within 2 min of normal saline irrigation. There were no significant complications during and after the procedure.

CONCLUSION: PSWL is a safe and effective method for fragmenting impacted stones in the bile duct system.

Key words: Impacted stone; Plasma shock wave lithotripsy; Choledochofiberscopy

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INTRODUCTION

Primary bile duct stones, especially intrahepatic ones, are common findings in Asian patients and challenging problems encountered in biliary surgery[1,2]. Retained and recurrent stones represent the two main problems in the surgical treatment of stones. With the application of intra- and postoperative choledochofiberscopy, the incidence of retained stones after surgery has been markedly reduced. Though many postoperative remnant stones can be extracted via choledochofiberscopy, it remains difficult to extract impacted stones or very large stones[3]. Impacted stones preclude insertion of the Dormia basket and cannot be captured with conventional techniques via choledochofiberscopy. Since large stones cannot pass through the T-tube fistula, it is both time consuming and frustrating to remove such stones. In order to solve this problem, we combined plasma shock wave lithotripsy (PSWL) with choledochofiberscopy. Both *in vitro* and *in vivo* studies have been conducted since the 1980s to test the safety and efficacy of this technique and the combination is widely used in clinical practice[4].

MATERIALS AND METHODS

Patients

From September 1988 to April 2005, 67 patients (26 men and 41 women) with impacted stones or very large stones in the bile duct system underwent PSWL in combination with choledochofiberscopy in our hospital. The mean age of the patients involved was 53 ± 3 years (range, 26 - 83 years). Of the 67 patients, 3 had a diagnosis of acute cholecystitis with cholelithiasis and previously underwent cholecystostomy with tube drainage, 36 patients had choledocholithiasis and underwent choledocholithotomy and common bile duct exploration with T-tube drainage, and 28 patients had a diagnosis of hepatolithiasis with or without stones in the extra-hepatic bile duct and received common bile duct exploration, intrahepatic bile duct stone removal via the common bile duct with the use of stone

Table 1 Sites of impacted or huge remnant stones

Sites	Impacted stones, *n* (%)
Distal end of common bile duct	22 (10.9)
Common bile duct	14 (7.0)
Cyst duct	3 (1.5)
Hilus of hepatic duct	10 (5.0)
Left hepatic duct	24 (11.9)
Left internal hepatic duct	71 (35.3)
Left external hepatic duct	8 (4.0)
Right hepatic duct	14 (7.0)
Right anterior hepatic duct	3 (1.5)
Right posterior hepatic duct	32 (15.9)
Total	201 (100)

forceps and partial hepatectomy as well as T-tube drainage when necessary. No cholangiocarcinoma was encountered in these patients. In our study, 39 patients were transferred from other hospitals. About eight attempts or so were made to extract choledochofiberscopic stones. Twenty-eight patients were admitted to our hospital at the beginning of their treatment.

Methods

All the patients underwent PSWL combined with choledochofiberscopic stone extraction without any anesthesia or sedation. The drainage tube was removed from the gallbladder or from the common bile duct, and a flexible choledochofiberscope (model CHF-T20), 6 mm in diameter with a 2.6-mm working channel (Olympus, Tokyo, Japan), was inserted through the drainage fistula into the gallbladder or the bile duct system. Once the impacted or large remnant stones were found, the PSWL probe (co-designed by the Institute of Physics at the Chinese Academy of Sciences and the Department of Surgery at the Third Hospital of Peking University) was inserted into the sites of the stones through the working channel of a choledochofiberscope. The tip of the PSWL probe (length, 100 cm; diameter 2 mm, flexibility similar to that of the catheter of Dormia basket) was targeted at the impacted stones and kept approximately 5 mm away. On the basis of the build-in PSWL circuit, the voltage switch was set at 2.5 - 3.5 kV and the energy output at 2 - 3 J for each pulse of PSWL. The number of PSWL pulses sufficient to break down a stone varied in each case. The treatment was continued until the impacted stones were fragmented sufficiently by PSWL to permit extraction with the Dormia basket (Olympus, SCOP Medicine, Tokyo, Japan) or passage into the duodenum via the sphincter of Oddi with normal saline perfusion. The bile ducts were irrigated during the procedure with normal saline and gentamycin, 4 U per 500 mL of normal saline, through the working channel of a choledochofiberscope[5].

RESULTS

In the 67 patients, 201 impacted or very large remnant stones were found in the bile ducts. The locations of stones are shown in Table 1. The gross appearance of the stones (39/201, 19.4%) found in the extrahepatic bile duct was consistent with that of the cholesterol stones. The stones found in the intrahepatic bile duct (162/201, 80.6%) resembled the pigment stones. We measured the size of impacted stones by direct visualization on cholangiogram. No difference in stone size was found between cholesterol and pigment stone groups. The size ranged from 5 to 50 mm in diameter, with 16 stones smaller than 10 mm, 167 stones between 10 and 20 mm, 16 between 21 and 30 mm, and 2 larger than 30 mm in diameter, respectively.

In our study, 199 of the 201 stones in the extra- and intrahepatic bile ducts of 67 patients were fragmented successfully by PSWL, and then extracted under a choledochofiberscope. Each PSWL procedure took several minutes to half an hour. The success rate of fragmentation with PSWL was 99.0% (199/201). Twenty-one stones required fewer than 10 pulses of PSWL sparks for fragmentation, 65 stones 11 - 50 pulses, 78 stones 51 - 100 pulses and 37 stones more than 100 pulses. The maximum number of PSWL sparks required was 700 pulses and the minimum was only two. The average number of pulses used was 52 ± 151.

Of the 201 stones, two were not fragmented by PSWL, one remained unfragmented though four procedures of PSWL totaling 1 063 pulses were carried out. A repeat operation was necessary for this failed PSWL. A huge impacted hard stone, 50 mm in diameter, was found in the left internal hepatic duct, which was not amenable to extraction with stone forceps. The left hepatic duct was opened and the large pigment stone was eventually extracted via a bile duct incision. Another impacted stone in the neck of the gallbladder was not fragmented by PSWL because the patient refused to fragment it by PSWL. Cholecystectomy was performed for this patient at last and the tightly impacted cholesterol stone was extracted from an incision at the neck of the gallbladder.

In 65 of the 67 patients, the fragmented stones were extracted successfully using a Dormia basket which was inserted into the bile duct through the working channel of a choledochofiberscope. The stone clearance rate was 97% (65/67). In 35 patients, only one choledochofiberscope procedure was needed to achieve clearance of remnant stones, whereas 22 patients required 2 to 5 procedures, 7 patients 6 to 10 procedures and 1 patient 18 procedures. The average number of procedures was 2 ± 41. A total of 171 procedures were performed.

In the process of fragmenting stones with PSWL via choledochofiberscopy, all the patients felt vibration. Ten patients felt mild pain in the right upper quadrant of the abdomen and could tolerate it well. Eleven patients had a small amount of bleeding from the mucosa of the extra- and intrahepatic bile ducts. It was thought that the bleeding was induced by the pulse of PSWL sparks. The bleeding was transient and stopped spontaneously within 2 min of normal saline irrigation. No other serious PSWL-related complications occurred during and after the procedure.

DISCUSSION

Impacted stone is one of the challenging problems in biliary surgery. Before the advent of PSWL, impacted stones or very large stones were removed using biopsy forceps through the working channel of a choledochofiberscope. The procedure is time-consuming and often frustrating. To solve this problem, we designed the PSWL in 1980s and have conducted a series of experiments both *in vitro* and *in vivo* to test its safety and efficacy before its application in clinical practice. Fresh cholesterol and pigment stones can be fragmented effectively both *in vitro* and *in vivo* by PSWL[4].

Plasma shock wave lithotripsy uses magnetic pressure ($F = B^2/8\pi$) exerted on plasma. The plasma shock wave is derived from the magnetic pressure. The total magnetic energy is constant. Since magnetic field B can be increased by decreasing the area in which B exists, a stronger wave can be achieved with low energy. PSWL has three advantages. First, there is no impulse to luminal wall when PSWL is used to break down gallstones within the lumen. Second, when PSWL is combined with choledochofiberscopy, there is no heat injury and no vapor to obscure the visual field of a choledochofiberscope due to its low energy. Third, PSWL has its selection when it acts on an elastic buffer. Fragmentation of gallstones is achieved by impulsion of PSWL. When impulsion acts on elastomer, the fragmentation is selective. Therefore, PSWL can effectively break down nonelastic stones, while leaving the elastic soft tissue intact[5].

In our study, 38 impacted or large cholesterol stones and 161 pigment stones were fragmented successfully by PSWL in the extra- and intra-hepatic bile ducts. The success rate of fragmentation was 99.0% (199/201), and the success rate of stone clearance was 97% (65/67).

Only two stones were not fragmented by PSWL. One impacted stone in the intrahepatic bile duct could not be fragmented by multiple procedures of PSWL with a total of 1 063 pulses of PSWL sparks delivered. Re-operation was performed for the involved patient, and the stone was too hard and too large (diameter, 50 mm) to be fragmented and extracted with stone forceps. The intrahepatic bile duct was opened and the stone was removed manually. Another cholesterol stone at the neck of the gallbladder was not fragmented by two procedures of PSWL with 84 pulses of PSWL sparks delivered. Cholecystectomy was performed for this patient, and a large hard cholesterol stone (diameter, 30 mm) at the neck of the gallbladder was removed.

In the present study, we successfully fragmented 199 impacted stones in extra- and intrahepatic bile ducts using PSWL when the conventional methods failed to remove them. The voltage switch was set at 2.5 - 3.5 kV, and the energy output was controlled within the range of 2 - 3 J at each pulse of PSWL. It may be very difficult to put a choledochofiberscope at the site of an impacted stone due to branches, strictures and angles of intrahepatic bile ducts. Therefore, it is unavoidable to spark directly on the impacted stone and the wall of bile duct in performing lithotripsy. In our study, 11 sites of intrahepatic bile ducts were sparked directly using the PSWL probe. Minor bleeding from the inflammatory mucosa of the bile duct occurred, and the bleeding stopped spontaneously within 2 min. No serious complications were found during and after the treatment, indicating that PSWL is a very safe method for breaking down stones *in vivo*.

The PSWL probe is flexible and can be easily placed at the site of impacted stones to fragment the stones through the working channel of a choledochofiberscope. The position of the probe tip can be adjusted by pulling it back and forth through the working channel. The best position is 5 mm away from the stone. At this position, the PSWL probe can release energy most effectively.

Electrohydraulic shock wave lithotripsy (ESWL) and PSWL have their similarities and differences. Using discharge in fluid to induce high-amplitude hydraulic pressure waves of varying wavelengths, ESWL can fragment stones extracorporeally or intracorporeally. The extracorporeal lithotriptor uses the ellipsoid reflector to reflect the shock wave into the intracorporeal site to break down the stones. The ellipsoid reflector has two focus points. One is extracorporeal, where the shock wave is emitted by discharge. The other is intracorporeal, where stones are located. Stone fragmentation and clearance rates of 76%[6] and 92%[7] have been achieved. Our study showed that PSWL was more effective than ESWL.

It was reported that the overall complication rate for ESWL is 13.2% - 22%[7,8]. Bleeding and perforation are the main problems. Perhaps the power of ESWL is strong enough not only to fragment stones, but also to damage the bile duct wall. Harrison *et al* [9] reported that to avoid grave complications, the ESWL probe should not directly contact the bile duct wall. However, PSWL may safely break down the stones without damaging the bile duct wall when the PSWL probe is in contact with the bile duct wall, suggesting that the safety of PSWL is superior to that of ESWL.

Laser has been used to fragment stones in common bile duct[10] and intrahepatic bile duct[11,12]. Orii *et al* [11] reported that yttrium-aluminum laser has enough power to crush pigment stones, but its efficacy on cholesterol stones is not satisfactory. Prat *et al* [13] reported that bile duct stones can be fragmented by laser lithotripsy. The overall success rate for stone clearance is 87.5% and the complication rate is 18.8%. Harris *et al* [14] reported that the success rate for fragmentation of stones by laser lithotripsy is 96%, whereas the complication rate is 28%. The complications may be due to the impact of laser fiber tip on the bile duct wall[13]. Therefore, care must be taken to advance the laser filament to the end of the scope, with the scope straight outside the patient. The relatively rigid, sharp filament may perforate the side wall of the working channel if it is advanced with force through a bent scope. Firing the laser, while the tip of the filament is inside the working channel can also damage the lining of the channel[14]. These shortcomings limit the efficacy of laser lithotripsy. Hochberger *et al* [10] have strongly suggested that laser can be used in the gallbladder and common bile duct, but not in intrahepatic duct. In terms of safety, PSWL is also superior to laser. The use of mechanical lithotripsy is limited to the treatment of stones in the common bile duct and in the gallbladder. It cannot be used to treat intrahepatic bile duct stones[15]. Ultrasound lithotripsy is limited to break down stones in the gallbladder because it cannot reach the bile duct[16].

In conclusion, PSWL is a very safe and effective method for *in vivo* fragmentation of impacted stones or large remnant stones. The PSWL combined with choledochofiberscopy, can fragment and clear most stones when a choledochofiberscope is inserted into the bile duct system.

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