

Electrohydraulic lithotripsy of gall stones – in vitro and animal studies

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SUMMARY Electrohydraulic lithotripsy of human gall stones was investigated *in vitro* in a bath of saline and in a saline perfused bile duct. The technique was effective – only two stones could not be shattered. Electrohydraulic lithotripsy power requirement correlated with mechanical strength of stones, but not with biochemical composition. A trend toward higher power requirement was recorded with larger stones and stones over 2 cm in diameter could not be fragmented. Safety studies indicated that electrohydraulic lithotripsy was safe, provided the probe tip was not in contact with the bile duct wall. *In vivo* studies did not show any late effects after 10 days. Electrohydraulic lithotripsy is likely to be useful in the management of biliary calculi.

Electrohydraulic lithotripsy was developed in the Soviet Union 35 years ago as an industrial technique for fragmenting rocks. The electrohydraulic lithotripter has two main components: a generator which produces a series of high voltage electrical impulses at 50–100 per second by means of capacitors. The generator we have studied (ACM) produces a pulse with a peak energy value of approximately 1 joule. The second component is a flexible 9 FG single use probe (a 5 FG version is also available) with two coaxially insulated electrodes ending at the open tip which acts as a sparking chamber. Each spark lasts approximately 1 microsecond and when discharged in 0.9% saline vaporises the fluid resulting in high amplitude hydraulic pressure waves of varying wavelength which fragment solid objects in their path. The generator can be adjusted to produce either single, double, or triple pulses such that the duration of the pressure wave may be varied. Electrohydraulic lithotripsy was first applied medically to the management of bladder stones.¹ This led to the widespread use of electrohydraulic lithotripsy for stones within the bladder,² ureter,³ and renal pelvis.⁴

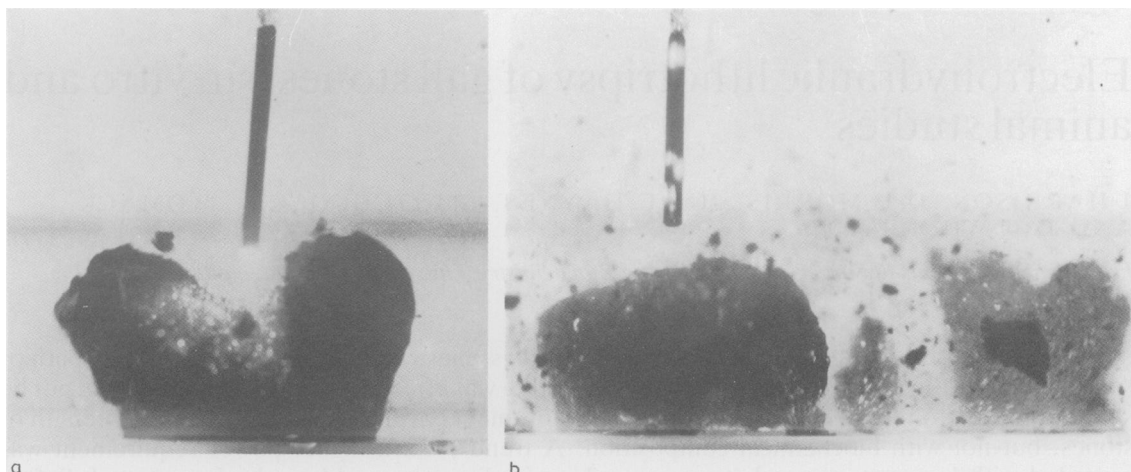
There are several clinical problems to which

electrohydraulic lithotripsy of gall stones may contribute. At present extraction of large or difficult common bile duct calculi is aided by the Dormia basket either from above or below⁵ or balloon catheter;⁶ however, both techniques have limitations. The electrohydraulic lithotripsy device was first used in the biliary tree by Burhenne⁷ to fragment a large retained common bile duct stone through a T tube track. Koch⁸ used a 9 FG probe through a special large channel duodenoscope to fragment common bile duct calculi. Electrohydraulic lithotripsy has also been used percutaneously through the liver to fragment common bile duct stones with a 4.5 FG electrode.^{9,10}

To date however, little data are available on the *in vitro* efficacy of electrohydraulic lithotripsy, in a recent study¹¹ only seven stones were studied and no measurement of mechanical strength or biochemical composition was made. While some acute animal experiments on safety were done in the same study, no one has studied any possible later effects of electrohydraulic lithotripsy on the bile duct. Extra corporeal shock wave lithotripsy has recently gained popularity in the management of renal stones and the shock wave produced is identical (but much more powerful) to that produced by electrohydraulic lithotripsy. These studies may therefore also indicate the suitability of gall stones for this form of treatment.

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Figs 1 (a) Photograph of probe tip during lithotripsy showing the spark together with splitting of the gall stone: (b) Slightly later many fragments are seen.

The aims of this study were to investigate the *in vitro* use of electrohydraulic lithotripsy in fragmenting gall stones and to compare electrohydraulic lithotripsy power requirement with the chemical composition and mechanical strength of stones.

Methods

IN VITRO ELECTROHYDRAULIC LITHOTRIPSY

Fresh human gall stones of known diameter were placed into a bath of 0.9% saline after measurement of diameter with a micrometer. The tip of the electrohydraulic lithotripsy probe was placed approximately 1 mm from the stone, and the spark voltage was increased stepwise (60, 80, 100, and 120 V) with a single, double, triple, and then continuous sparks until the stone fragmented (Fig. 1). The single, double, and triple 'sparks' are measurements of the length of the discharge.

The amount of force required to crush stones of similar diameter from the same patients was measured with a digital mechanical press. Chemical analysis of the stones was done for calcium using the Calcein method, for bilirubin with a spectrophotometer and for cholesterol using gas liquid chromatography.¹²

INTRA-DUCT ELECTROHYDRAULIC LITHOTRIPSY

To determine the efficacy of electrohydraulic lithotripsy in the bile duct, the probe and gall stone were placed within ovine and human cadaver bile ducts which were perfused with 0.9% saline through a cannula in the cystic duct. The studied bile ducts consisted of the extrahepatic portion from porta hepatis to duodenum. The duct in each case was from

a normal biliary tree, with the sheep and human ducts being similar in size and wall thickness.

The amount of energy required to fragment the stone was recorded and the duct was inspected for evidence of macroscopic damage.

DUCT SAFETY

Five lengths of human bile duct were opened and tied over a frame immersed in a bath of saline. The probe was then held at measured distances from the duct (1–5 mm) using a specifically designed jig to fix the position of the probe a measured distance from the duct wall. A range of energy settings was expended upon the duct, which was examined for signs of perforation by naked eye inspection. The effect of firing the probe in direct contact with the duct wall was also assessed.

IN VIVO ELECTROHYDRAULIC LITHOTRIPSY

To determine the safety of electrohydraulic lithotripsy *in vivo*, fresh human gall stones (approx 5 mm) were placed into the gall bladder of five anaesthetised rabbits and then subjected to electrohydraulic lithotripsy within the gall bladder at laparotomy. A further five rabbits acted as a control group, in whom gall stones were placed within the gall bladder and then removed but electrohydraulic lithotripsy was not performed. The amount of energy and the number of sparks required to fragment the stone was recorded and the resulting fragments were removed. The gall bladder and abdominal wounds were closed and the animal allowed to recover. A post mortem examination was carried out at 10 days and the gall bladder examined histologically in order that data could be obtained and the long term safety of

electrohydraulic lithotripsy could be determined in living tissue.

Results

IN VITRO ELECTROHYDRAULIC LITHOTRIPSY

Forty fresh human gall stones were subjected to electrohydraulic lithotripsy and the relationship of stone diameter to electrohydraulic lithotripsy power setting is seen in Figure 2. The median stone diameter was 11 mm (range 5–28 mm) and the median fragment diameter was 4.5 mm (range 1–11 mm).

Twenty six of the 40 (65%) fragmented with a single spark. Two stones could not be fragmented by electrohydraulic lithotripsy (24, 28 mm). No clear relationship between stone size and electrohydraulic lithotripsy power requirement was seen, and similarly no relationship to chemical composition was found (Table 1). Cholesterol content ranged from 0–62%, bilirubin from 0–7% and calcium from 0.02–2.02%. Electrohydraulic lithotripsy power required, however, did correspond with mechanical strength of stones ($p=0.01$) (Spearman coefficient=0.927) (Table 2).

INTRADUCT ELECTROHYDRAULIC LITHOTRIPSY

Five stones were subjected to electrohydraulic litho-

Table 1 Chemical composition compared with EHL power requirement

Stone	Dry weight (%)				EHL
	Calcium	Bilirubin	Cholesterol	Residue	
1	0.51	0.13	62	37	F
2	0.81	0.03	48	51	80 VT
3	0.28	0.2	56	43	60 VD
4	1.7	0.05	32	66	100 VS
5	2.02	2.03	28	67	60 VS
6	0.02	0.06	51	49	100 VS
7	1.08	7.06	0	91	100 VS
8	2.27	5.31	<1%	91	60 VS

EHL=electrohydraulic lithotripsy; F=failure; S=single EHL; D=double; T=triple; V=volts.

tripsy within a perfused bile duct, and all of these were fragmented with a single spark. The median stone diameter was 6.7 mm (range 6–7 mm.)

DUCT SAFETY

It was found that the bile duct wall could not be damaged at any power setting when the probe tip was 1 mm or more away from the duct. When the probe was placed in direct contact with the duct wall the spark energy vapourised the wall, resulting in perforation at even the lowest power setting.

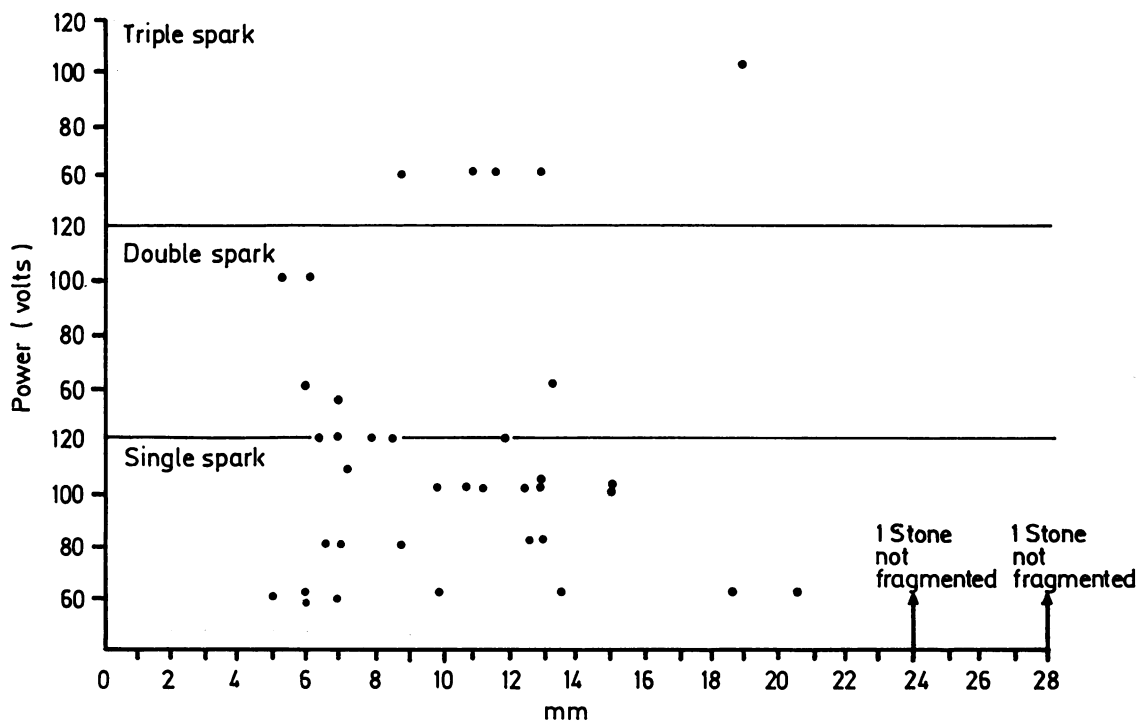


Fig. 2 Comparison of EHL power requirement and diameter of stones.

Table 2 Stone diameter compared with EHL power and mechanical strength

Max diameter (cm)	EHL power (volts)	Crushing force (kg)
1 10.5	100	0.84
2 8.7	100	1.01
3 24	F	2.17
4 10	100	1.07
5 9	100	0.65
6 10	100	0.5
7 10	100	0.56
8 7.4	100	2.15
9 13	100	1.6
10 7	150	2.78

EHL=electrohydraulic lithotripsy; S=single EHL; D=double EHL; Kg to crush=mechanical force required to split stone; F=failure.

IN VIVO ELECTROHYDRAULIC LITHOTRIPSY

The gall stones were easily fragmented within the gall bladder, up to 5 sparks were required. The rabbits treated by electrohydraulic lithotripsy showed no major microscopic difference from sham treated controls, all had some degree of gall bladder inflammation but there was no perforation or other evidence of delayed gall bladder or bile duct damage.

Discussion

Electrohydraulic lithotripsy has been shown to be an effective method of fragmenting human gall stones, both *in vitro* and in an animal model. Human gall stones were equally easily fragmented in a container or within cadaver extra hepatic bile ducts perfused with saline. Duct injury was only seen when the end of the probe was in direct contact with the duct wall, probably because of thermal injury from the spark itself rather than any effect of the shock wave.

A correlation between the electrohydraulic lithotripsy power required and mechanical crushing force needed to fragment stones was seen ($p=0.01$), and a trend to higher power requirements for larger stones just failed to achieve significance. The only two stones which could not be fragmented were both above 2 cm in diameter although other large stones were easily broken by electrohydraulic lithotripsy. No correlation with chemical composition and electrohydraulic lithotripsy power was seen.

One of the most important considerations in the development of electrohydraulic lithotripsy in the biliary system is safety, and we are encouraged by both the *in vitro* and animal studies; in the latter experiment no late damage was seen. We specifically looked at 10 days to ensure that no delayed damage occurred when we had established that electrohydraulic lithotripsy was safe in *in vitro* studies provided the probe was 1 mm from the duct.

It must be noted, however, that direct contact

between the probe and duct wall must be avoided. There are several possible clinical applications of electrohydraulic lithotripsy in the biliary tract. A long electrohydraulic lithotripsy probe is now available and can be passed through a duodenoscope and through the papilla to fragment stones which are resistant to conventional extraction techniques after papillotomy. Perioperative electrohydraulic lithotripsy using a choledochoscope may sometimes be useful for a difficult impacted bile duct calculus. The probe is so small that transhepatic passage is likely to be feasible and could be used for both gall bladder and bile duct stones.

Extracorporeal shock wave lithotripsy where the shock wave is generated outside the body but is transferred by immersing the body and generator in fluid, has rapidly gained popularity in the management of renal stones. The principle is exactly the same as electrohydraulic lithotripsy and can be expected to be effective for biliary calculi.

Electrohydraulic lithotripsy is well established in the treatment of urinary tract calculi. The generator units are relatively inexpensive (approximately £1000), easy to use and appear reliable. Probes can be used more than once but have a finite life. It has recently been reported¹³ that pulsed Nd YAG laser energy can fragment gall stones but is considerably more expensive and may produce duct injury even when the tip of the probe is not in direct contact with the duct wall. The findings of this study suggest that electrohydraulic lithotripsy may also be useful in the biliary tree.

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