Review Article

Extra-corporeal shock wave lithotripsy

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Summary: Extra-corporeal shock wave lithotripsy (ESWL) has proved to be a revolutionary advance in the treatment of renal stone disease. It, itself, is non-invasive but may necessitate or be used as an adjunct to more invasive auxiliary procedures. The basic principles of lithotripsy, the clinical experience thus far and probable future applications are discussed.

Introduction

The incidence of upper urinary tract disease is usually expressed as the number of cases seen in a hospital per 100,000 admissions to the hospital.¹ Recent work suggests that the best estimate of the incidence of renal stone in England and Wales is 28 per 100,000.² A random population survey in Scotland reveals a prevalence rate of 3.4%³ and with no difference in stone prevalence between males and females³ as distinct from treated stone patients. In other countries epidemiological studies suggest even higher figures. Yet despite diligent search for alternative methods, open surgery had been the treatment of choice for renal stone until 1980. True, chemotherapy had been tried but this was restricted to uric acid calculi and in any event had proved less than successful. Direct contact between ultrasound or electrohydraulic shock waves proved effective but was limited in application to the lower urinary tract as the closest approximation between stone and energy source was desirable.

In 1963 Dornier, the West German manufacturing company, undertook an extensive research programme on the shock waves generated by rain drops falling on the wings of their fighter aircraft during high-velocity flight. They were also actively investigating the effects of micro-meteorite impacts on the walls of orbiting spacecraft. This research showed that the shock waves produced by both these phenomena were of high amplitude and were propagated to a large extent according to the known physical laws of wave transmission in both solids and fluids. In 1966 an engineer working for the Dornier company touched a shock wave target and felt a sensation akin to an electrical

shock. This accident stimulated further research. The Federal Ministry for Research in conjunction with both Dornier and the Institute for Surgical Research at the Grosshadern Clinic in Munich undertook a comprehensive scientific research programme to pioneer a shock wave apparatus for the treatment of renal calculi. The shock waves would be generated outside the body, focussed on the renal calculus and would act as a sufficiently disrupting force to permit the passage of the debris down the ureter and into the bladder.

Physical principles

In the Dornier system, shock waves are generated underwater by the spark discharge of a high voltage condenser. This condenser discharge lasts one micro-second and causes the explosive evaporation of water which in turn expands rapidly and generates shock waves. The waves are focussed by placing the electrode in the geometric focus of an ellipsoidal reflector. The geometrical properties of the reflector mean that an expanding shock wave initiated at one of its focal points will be focussed after reflection at its second focal point (Figure 1). This is the point of highest energy density and the patient's stone must be brought to lie at this point (Figure 2).

The shock wave passes evenly through the body tissues since the acoustic impedance of most body tissues is close to that of water and encounters the anterior surface of the stone. Here it is in part absorbed and in part reflected. This leads to the formation of pressure gradients, due to the sudden

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Figure 1 Elipsoidal reflector focussing shock waves.

change in acoustic impedance with the resulting shear and tear forces disintegrating zone A (Figure 3). Zone B next comes under the influence of similar forces generated by the shock waves being reflected from the posterior surface of the stone and it is the second area to be disrupted. These two zones overlap until finally the disruptive force destroys the calculous material in zone C. With the Dornier system the peak positive pressure of a single shock wave has been measured at 40 megapascals (1 MPa is approximately 6000 lb/sq inch). Animal experiments showed tissue damage to be

insignificant except in the lungs and in 1980 Chaussy and his colleagues⁴ reported their first series of treatments in animals to be followed two years later by their report of successful patient treatments.⁵ The importance of patient selection was stressed. (a) The patient must weigh less than 130 kg and be taller than 1.2 metres. These limitations are imposed by the hydraulic stretcher. (b) The stone must be clearly visible on the X-ray monitors. Ureteric stone may be pushed up the ureter into the renal pelvis before treatment – the so-called ‘push bang’ technique. (c) There must be no distal obstruction to impede the passage of the resulting fragments.

The equipment and its usage

The Dornier Lithotripter (Figure 4, a and b) consists in essence of the shock wave generator, a biplanar X-ray imaging device for localization and correct positioning, and a hydraulic stretcher hoist. The treatment is painful and has to be performed under either general or local (epidural/spinal) anaesthesia. General anaesthesia has the advantage of being quick and reliable. It also allows the use of high frequency jet ventilation to

Figure 2 Method of extra-corporeally induced shock waves being focussed on a kidney stone.

Figure 3 Mechanism of disintegration of a stone by shock waves. The direction of the arrows indicates the pressure gradients and the resultant shear and tear forces.

minimise stone movement – a factor which may be important in stone placement in the target zone and in increasing the ‘hit-rate’ of the applied shock waves. It is, however, accompanied by a high incidence of post-operative nausea and sore throat. The use of epidural or spinal anaesthesia avoids these latter problems and also enables patients to assist in their placement in the hoist. Unfortunately a longer preparation time is required and even sensory blockade to the T5 dermatomal level does not guarantee complete analgesia during the procedure.⁶ Once anaesthetised the patient is placed in the hoist which in turn is lowered into the water bath. The patient is moved during X-ray screening until the stone is seen to lie at the centre of the crosswires of each television monitor. Treatment

then begins. The discharge of the shock wave is synchronised with the heart beat by means of an electrocardiogram (ECG) output fed into the shock wave generator: the shock wave is triggered by the R wave of the patient’s ECG. The disintegration of the stone is monitored at regular intervals using the biplane image intensification system. The total X-ray dosage the patient receives is comparable to a cardiac catheterization. The images are stored on the television monitors. The total number of shocks will depend on the stone’s size and chemical composition; in our own series an average of 1,500 shocks is necessary.⁷ Clinical experience has shown that whilst the great majority of renal stones can be disrupted in this way difficulties do arise with cystine stones which

Figure 4 (a and b) The Dornier Lithotripter showing the shock wave generator, the bi-planer X-ray imaging device, the hydraulic stretcher hoist and the water bath.

do not seem to disintegrate adequately. Furthermore, stones over 3 cm in diameter produce so much debris that the ureters capacity to excrete the fragments is often surpassed, leading to obstruction. Such stones are probably best treated by the insertion of a ureteric stent prior to lithotripsy, otherwise percutaneous nephrostomy drainage or ureteroscopy may be required. The former enables the ureter to regain its peristaltic activity, the latter affords extraction of the fragments. Following the initial break through in this field by Dornier, further development has produced less cumbersome and more cost effective equipment. Some of these such as the Siemen's Lithostar still use a biplane X-ray system for stone localization and orien-

tation, but the new system, which in many ways resembles a modified and adapted urological table, permits a wider range of application. These include percutaneous nephrolithotomy, ureterorenoscopy and cystoscopy. The shock wave unit components are also more economical. The unit is based on the electromagnetic principle and the generator can be switched as desired between 2 shock wave heads. The water bath is dispensed with (Figure 5).

Development has also progressed along an entirely different line. Here kidney stone fragmentation is based on the physical properties of high energy pulses generated and radiated from a dish fitted with a mosaic of piezo elements (Figures 6 and 7). This dish-

Figure 5 The Siemens Lithostar, a second generation machine for renal stone treatment and allied procedures.

shaped piezotransducer is excited by a pulse generator which allows operation either with single pulses or with continuous pulses. There are four such levels of pulse intensity which enables different sonic pressures to be achieved at the focal point. This transducer is situated below an opening in the surface of a mobile operating table. The dish is filled with de-gassed water at body temperature. This serves as the interface for

the application of shock waves. The patient is so positioned that the area to be treated covers the opening and is immersed in the water. The location of the stone and the monitoring of its fragmentation is achieved using an ultrasound real time scanner. It is stated that the piezo-electric disintegration of stones is painless and unlike earlier lithotripters can be achieved without anaesthetic and without ECG triggering.

Piezoelectric lithotripter

Figures 6 and 7 The Wolf Piezoloth. The dish-shaped piezotransducer is excited by a pulse generator. The high energy pulses are focussed on the stone.

Table I Results of ESWL treatment (worldwide)

	<i>Munich</i>	<i>Stuttgart</i>	<i>Sapporo</i>	<i>UCLA</i>
Date of opening	2/80	10/83	9/84	3/85
Success rate	99.0%	99.0%	99.0%	99.5%
Stone free	85%	85%	77%	80%
(3 month follow up)				
Spontaneously passable	11%	11%	19%	16%
Residual fragments	2%	4%	3%	4%
> 4 mm				
Open surgery	1%	0%	0.55	0%
Complications				
Fever	6%	3%	5%	4%
Pain/Colic	25%	28%	32%	22%
Auxiliary measures	16.4%	17.6%	15.8%	19.0%
Pre ESWL	5.1%	10.3	4.4%	12.2%
Post ESWL	11.3%	7.3%	11.4%	6.8%

(Data from Chaussy, Ch. & Fuchs, G.I. World experience with extra-corporeal shock wave lithotripsy for the treatment of urinary stones. An assessment of its role after 5 years of clinical use. *Endo-urology* 1986, 1: 7.)

There are, in addition, a number of other advantages, namely the low operating cost as there is no wear and tear on the piezo mosaic, and minimal installation cost. A disadvantage of the piezotransducer system may be that the pressures achieved will not be sufficient to disrupt larger stones. This may prove to be particularly true with stones in the upper poles of the kidney which will be more difficult to visualize using ultrasound.

A further exciting development is the application of a modified Dornier machine in the treatment of gall stones⁸ and the firm belief that in the very near future the piezo-electric principle will be used in this field also.

Results of extracorporeal shock lithotripsy treatment

For extracorporeal shock wave lithotripsy to be successful, the calculous material must not only be disrupted but must also be passed spontaneously and completely. Follow-up abdominal radiographs augmented if necessary by tomography, must show the patient to be free from any residual calculous debris. The initial experience was with carefully selected patients and success rates of over 90% were recorded.⁹ Success however is related to the site, size and composition of the stones. Smaller stones in the renal pelvis are the easiest to deal with and the most amenable to treatment. Table I shows the success that may be achieved by careful selection with regard to both stone size and site.

Our own experience is similar to that of the workers at the New York Hospital documented by Riehle and Näslund.¹⁰ They confirmed the greatest success is

with solitary stones in the renal pelvis (91%), the lowest stone free rates are with multiple large calculi (43%) and full staghorn calculi (50%).

ESWL is a safe procedure with a low mortality rate. One related death from septicæmic shock occurred in the first 2,000 cases done on the BUPA/St. Thomas's lithotripter.¹¹ Whilst small stones can be dealt with as a primary procedure, larger ones often necessitate an auxiliary procedure, such as the pre-treatment insertion of a ureteric stent or post-treatment placement of a nephrostomy or ureteroscopy; staghorn calculi are best treated by percutaneous nephrolithotomy to debulk them followed by ESWL. A second treatment for complete removal of calculous material was required in some 8% of cases.⁷ The average hospital stay is only about four days and on discharge the patient may resume his normal lifestyle immediately.

Figure 8 Transient bruising of the skin following successful shock wave treatment.

There is no disfiguring scar and a transient bruising of the skin (Figure 8) is usually the only visible sequel to treatment although ultrasound studies show small and usually insignificant renal haematomas to be present in between 1% and 3% of cases.^{12,13} With increasing

research and development there is every hope that this revolutionary form of therapy will extend from the renal tract to the biliary tree and enable the effective treatment of gall stones to occur just as safely without surgery or scars.

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