Extracorporeal shock wave lithotripsy (ESWL) is a new, noninvasive technique of reducing renal stones to small particles that will pass through the urinary system. The patient is immersed in a tub filled with 37.5°C degassed water, and positioned with head, neck and uppermost chest above the waterline. An underwater shock wave aimed at the kidney stone causes it to disintegrate. Although a single shock wave is not painful, an average of 2400 shocks are usually required. Anesthesia is necessary for analgesia and to minimize patient movement. ESWL presents new challenges to the anesthetist due to the unique environment and remote patient monitoring inherent in this procedure. This paper reviews the authors' experiences in their first 200 patients undergoing general anesthesia for lithotripsy.

Extracorporeal shock wave lithotripsy (ESWL) is a new, noninvasive therapy to reduce renal stones to small particles. Anesthesia is required to attenuate pain and patient movement. ESWL opens new challenges to the anesthetist because the patient is immersed in water resulting in changes in cardiovascular and pulmonary parameters. Remote monitoring and unique patient positioning are also innate challenges in ESWL.

Surgery was the treatment for renal stones until the last decade. With the advent of percutaneous and ureteroscopic techniques, the need for open surgical procedures was decreased. Now, ESWL therapy has eclipsed prior forms of treatment. Clinical trials with the Dornier HM-1 lithotripter began on February 20, 1980, in West Germany. Since that time, more than 200,000 treatments have been performed worldwide. In communities where ESWL exists, less than 1% of stones are removed by means of conventional surgery.

**Methods**

A total of 200 patients undergoing ESWL under general anesthesia were studied. Each patient was seen and evaluated preoperatively and postoperatively by one of the three investigators. Preanesthetic notes were made and general anesthesia was discussed with each patient. Laboratory studies were done (complete blood cell count, urinalysis, electrolytes). A chest x-ray and ECG were performed on each patient over 40 years old. Appropriate premedication was administered.

Each patient was induced with sodium thiopental 4 mg/kg given in fractional increments. The patient was given atracurium 0.5 mg/kg and intubated, and was maintained on appropriate concentrations of isoflurane and 100% oxygen. The patient was carefully positioned in a semi-fowler position in the "gantry", a padded chair. The authors do not induce or intubate the patient in the gantry since the head of the gantry cannot be lowered in the event of vomiting.

Once the gantry has been lowered in the tub
of water, the patient's arms are allowed to float freely at his or her side. This prevents possible brachial plexus injury (which could occur if the arms were placed above the head). Chest and abdominal straps must be secure enough for patient safety, yet must allow for chest expansion. The authors utilize mechanical machine ventilation with a tidal volume (VT) of 5 cc/kg, at a respiratory rate of 15 breaths/minute. Patient ventilation was individualized by use of a capnograph. This approach seems to minimize stone movement related to ventilation.

Monitoring the patient's vital signs is a challenge due to the remoteness of the patient. The loud shock wave, occurring at the same rate and time of the heartbeat, prevents the use of the precordial or esophageal stethoscope. The authors' monitoring consists of precordial monitors (when not firing), ECG, oxygen analyzer, volume monitor, standard blood pressure cuff, noninvasive blood pressure monitoring, esophageal temperature, pulse oximeter and end-tidal carbon dioxide monitoring. The pulse oximeter is attached to the ear to keep it dry. ECG and IV sites are well protected with self-adhering plastic seals.

Postoperatively, the patients were evaluated in the recovery room and in the early evening on the ward. Many patients were discharged in the evening. Some patients were transported via ambulance back to their referring hospital. With adequate hydration and ambulation, the stone fragments were passed in the urine postoperatively.

In this patient series, the authors considered a 20% change from the preoperative baseline blood pressure to represent an unstable blood pressure. Abnormal induction ECGs were defined as dysrhythmias (i.e. ventricular bigeminy, ventricular tachycardia) persisting longer than two minutes after intubation. Intraoperative dysrhythmias were defined as the appearance of premature atrial, premature nodal, or more than two premature ventricular beats/minute. On the postoperative visit, patients were questioned as to the presence of sore throat, flank pain, nausea/vomiting, in addition to general well-being. Auscultation of the heart and lungs was again performed.

Results

Patients' ages ranged between 12 and 89 years (Table I). Patients classified as ASA physical status I comprised 16.9% of the group, while those categorized ASA II comprised 74.3%, and those categorized ASA III comprised 8.8%. There were no patients classified ASA IV or V included in this study (Table II). Pre-existing conditions of the 200 patients studied are listed in Table III. A total of 67% of patients had some history of cardiovascular problems, while 38.8% had some history of pulmonary problems. Those patients with nervous system disorders resulting in paralysis and/or decreased mobility constituted 5.5% of the total group. These patients required special consideration with regard to gantry positioning to prevent possible ischemic and/or skin trauma.

Intraoperative anesthesia presented a quiescent course as judged according to the authors' criteria for 93.3% of the patients studied. The most common complication was unstable blood pressure. While 8.2% had mildly unstable blood pressure during the induction phase, 11.2% had mildly unstable blood pressure intraoperatively. Abnormal ECG dysrhythmias occurred during 1.5% of the inductions and in 2% of the patients intraoperatively, with none of these requiring treatment. There was difficulty in ventilating 1.7% of the patients, manifested by 50 cm H2O+ needed to inflate the lungs. This problem was corrected by loosening the chest straps on the gantry.

Postoperative emergence from general anesthesia was described as satisfactory according to the authors' criteria in 99.4% of the patients. Two patients required treatment for unstable blood pres-

<table>
<thead>
<tr>
<th>Table I</th>
<th>Patient population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Number</td>
</tr>
<tr>
<td>10-19 years</td>
<td>4</td>
</tr>
<tr>
<td>20-29 years</td>
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<tr>
<td>30-39 years</td>
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<tr>
<td>70-79 years</td>
<td>20</td>
</tr>
<tr>
<td>80-89 years</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table II</th>
<th>Risk classifications for patients studied</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASA classification</td>
<td>Number of patients</td>
</tr>
<tr>
<td>I</td>
<td>33</td>
</tr>
<tr>
<td>II</td>
<td>145</td>
</tr>
<tr>
<td>III</td>
<td>17</td>
</tr>
<tr>
<td>IV</td>
<td>0</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
</tr>
</tbody>
</table>
sure. The first patient's blood pressure persistently stayed at 50% above the baseline and an IV nitroprusside drip was started. The second patient was treated with two IV doses of labetalol. Both of these hypertensive episodes occurred in the recovery room.

The greatest complaint postoperatively was sore throat (31.2%), which was attributed to endotracheal tube motion secondary to frequent repositioning of the patient. Almost all patients had some ecchymosis at the treatment site. Patients complaining of flank pain numbered 25.6%, while 13% of patients complained of nausea or vomiting. Upon aggressive postoperative nausea questioning of all patients, some degree of nausea was found to be present in 80%. There were no incidences of brachial plexus injury.

Three patients were cancelled preoperatively and later rescheduled; two of these were due to hypokalemia, and one resulted from sudden onset of atrial fibrillation.

The review of 200 patients revealed minimal complications as illustrated in Figure 1.

Discussion

The National Kidney Foundation reports that about 800,000 Americans are stone formers. Actually, kidney stones have plagued mankind for thousands of years. Archaeologists have unearthed a 7,000 year old mummy with an intact bladder stone. Benjamin Franklin was tormented by kidney stones most of his life. He tried everything from self-catheterization to standing on his head to dislodge the stones. Franklin preferred pain to surgery, and

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**Table III**

<table>
<thead>
<tr>
<th>System</th>
<th>Dysfunction and percent of affected patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>Smoker 26%</td>
</tr>
<tr>
<td></td>
<td>Asthma/Emphysema 4%</td>
</tr>
<tr>
<td></td>
<td>Bronchitis 6%</td>
</tr>
<tr>
<td>Nervous</td>
<td>Disorientation/Senility 1.5%</td>
</tr>
<tr>
<td></td>
<td>CVA/Parasthesia 2.5%</td>
</tr>
<tr>
<td></td>
<td>Muscle/Skeletal disorder 3.5%</td>
</tr>
<tr>
<td>Renal</td>
<td>Renal disorder 5.6%</td>
</tr>
<tr>
<td></td>
<td>Urosepsis 1.5%</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>CHF 0.5%</td>
</tr>
<tr>
<td></td>
<td>MI/ASHD/CAD 27%</td>
</tr>
<tr>
<td></td>
<td>Angina/Palpitations 2%</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Obesity 30%</td>
</tr>
<tr>
<td></td>
<td>Nausea 3.2%</td>
</tr>
<tr>
<td>Endocrine</td>
<td>Cirrhosis/Hepatitis 1.5%</td>
</tr>
<tr>
<td></td>
<td>Diabetes 5.6%</td>
</tr>
<tr>
<td></td>
<td>Thyroid/Adrenal disorder 1.5%</td>
</tr>
</tbody>
</table>

ASHD = arterial sclerotic heart disease
CAD = coronary artery disease
CHF = congestive heart failure
CVA = cerebral vascular accident
MI = myocardial infarction
little wonder. In the eighteenth century, more patients were killed than cured. In modern times, more than 300,000 patients have successfully undergone ESWL therapy for stone removal.

The Dornier Systems, an aerospace company, developed the technology of the lithotripter through an accidental discovery while experimenting with jet aircraft. When a jet flying faster than the speed of sound passed through a raincloud, the raindrops slamming against the fuselage created shock waves with enough energy to damage the surface of the aircraft. A chance conversation between Dornier engineers and Munich physicians led to the application of this discovery to medicine and the lithotripter was developed.11

The procedure employs an electrical spark generated under water; water conducts the wave three times better than air. The spark vaporizes the water, causing a shock wave. The shock wave is aimed and concentrated by means of an elliptical cup. This high energy wave travels through body tissue (a medium similar in acoustic impedance to water). At its focal point, the wave impacts against stone and liberates short-term, high energy mechanical stresses. This stress overcomes the tensile strength of the calculus, causing disintegration. A summation of wave impacts then pulverizes the calculus into sand in most cases. Voltage across the electrode determines the strength of each shock wave delivered. The amount can be varied from 18,000 to 24,000 volts. Only at the focal point (1.5 cc in volume), are maximal compression energies developed that disintegrate calculi of all compositions, while causing no demonstrable damage to surrounding organs or tissues.12 However, animal studies have revealed the kidneys to be enlarged, with intra-capsular hemorrhage.13 Lung tissue may be damaged owing to the vast area of air-water interfaces and its delicate architecture.14

The patient is immersed in a tub filled with 37.5°C degassed water, and positioned with the head, neck and uppermost chest above the waterline. To avoid a tissue-air interface, which could lead to tissue damage secondary to wave distortion, exit points as well as entrance points must be submerged. In early animal studies, ESWL was noted to cause extrasystoles; for this reason, the shock wave fires 20 milliseconds after the ‘R’ wave of the ECG. This puts the shock wave in the relatively depolarized time of the ECG, and has greatly reduced the number of cardiac arrhythmias.15 Since the shock wave generator is fixed to the bottom of the tub, the patient (and stone) must be maneuvered into focus. The patient is placed into the gantry, then lowered into the tank and positioned. The gantry is positioned by the use of fine hydraulic controls. Fluoroscopy is used when aiming the shock waves at the stone. Two fluoroscopy tubes, perpendicular to each other, visualize the stone.10

A single shock in not very painful, somewhat analogous to a blow to the flank. However, one shock wave cannot pulverize a stone; 2400 shocks might be needed. Since the zone of impact is only about 2 x 2 cm, the patient must remain still to allow the stone to remain in the relatively small impact area. For these reasons, anesthesia is required.

The most interesting anesthesia considerations are the unique problems associated with immersion of the patient in water almost to the neck; the cardiovascular and pulmonary systems may be affected. Most studies of these effects were described in the aerospace medical journals of the 1970s.17 With immersion, the water pressure compresses the blood out of the capacitance vessels of the abdomen and extremities, thereby increasing the central volume. One study reported the central vascular volume was increased by 700 cc. This caused a 32% increase in cardiac output and a 35% increase in stroke volume. Pulmonary capillary blood flow increased 25-35%.18 Weber has delineated similar cardiovascular changes.9

However, recently Behnia et al. reported a significant rise in systemic vascular resistance and a moderate rise in blood pressure.10 This study also found a slight decrease in cardiac output, using a transesophageal Doppler ultrasonic cardiac output monitor, which was attributed to the elevated systemic vascular resistance. With neck immersion, there has also been reported a marked natriuresis, kaliuresis and diuresis, as well as suppression of the renin-aldosterone system and ADH release.28

Dysrhythmias associated with ESWL sometimes occur. It is postulated that the direct effect of the shock wave on the heart is the basis for these dysrhythmias. Most of these dysrhythmias are of a supraventricular origin. Walts et al. found premature ventricular beats to be rare, but premature supraventricular contractions occurred in about 10% of their patients.7 A recent study found that plasma catecholamines or a history of cardiovascular disease did not correlate with the occurrence of dysrhythmias.8

Controversy exists regarding the effect of ESWL on pacemakers. Weber describes the potential hazards of ESWL on pacemakers and recommends that a cardiologist and a programmer be available during the procedure.9 Larcia encountered no problems with his pacemaker patients and suggested that
all the extraneous electrical energy was filtered and rendered harmless.\textsuperscript{10}

There are pulmonary problems inherent in the immersed patient. The hydrostatic pressure of the water, pressing in on the chest and abdomen, reduces the functional residual capacity by 30-35\% and the vital capacity is reduced by 25\%.\textsuperscript{22,24} In addition, when performing this procedure the authors intentionally reduce the tidal volume, as mentioned earlier, to minimize diaphragmatic or stone movement. All these factors would contribute to increased shunting, increased atelectasis and increased closing volume.

These pulmonary changes are sometimes manifested in a progressive fall in oxygen saturation as measured by the transcutaneous oximeter. This occurs especially in patients such as the very obese, smokers and those with chronic bronchitis. These types of patients have an elevated lung closing volume even prior to tub emersion. In these patients, the authors' practice is to minimize the pulmonary changes by deep sighing every 200 shocks, during quiescent periods of non-firing.

High frequency jet ventilation (HFJV) at a rate of 100-300 breaths/minute may be the preferred method of ventilation during ESWL, because the stone remains virtually stationary due to the low tidal volume.\textsuperscript{26,27} However, the use of HFJV in adults in the United States is restricted by the FDA to bronchopleural fistulas and pulmonary traumas. High frequency positive pressure ventilation (HFPPV) allows adequate gas exchange while minimizing stone movement. The Siemens-Elema system offers a convenient method of switching to HFPPV after the patient is in the gantry. Once HFPPV is begun a respiratory rate of 100 bpm and a $V_T$ of 1.5 cc/kg insures sufficient ventilation and improved focusing on the stone.\textsuperscript{28}

Recently, lithotripsy is finding innovative applications. In Florida, clinical trial studies are being conducted for ESWL treatment of gallbladder stones.\textsuperscript{29} In the authors' hospital, a lithotripter was fitted with an infant seat to facilitate the ESWL treatment of a seven-month-old baby, thus preventing surgery.\textsuperscript{29,30}

**Conclusion**

General anesthesia for the ESWL patient presents challenging problems to the anesthetist. There are novel physical considerations, namely the position and remoteness of the patient. Immersion of the patient in the tub causes significant cardiovascular and pulmonary parameter changes. A thorough knowledge of these considerations is vital to the successful anesthetic management of the ESWL.

**REFERENCES**


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