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Effect of Three Anesthetic Techniques on the Success of Extracorporeal Shock Wave Lithotripsy in Nephrolithiasis

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The optimal anesthetic technique for extracorporeal shock wave lithotripsy (ESWL) for nephrolithiasis has not been established.[1] It is sometimes intuitively assumed that the less the kidney and stone move, the more effective the treatment. Ventilation with small tidal volumes minimizes stone movement by reducing diaphragmatic and kidney excursion.[1,2] The assumption is that disintegration is more complete if more shock waves are focused directly on the stone.

Three different anesthetic techniques are used for ESWL at our institution, each resulting in a different tidal volume. We undertook this study to determine if the type of anesthesia and resultant degree of stone movement affected the success of ESWL therapy.

MATERIALS AND METHODS

We reviewed the records of 289 patients treated by ESWL for nephrolithiasis at our clinic between December 1985 and June 1986. Six-week urologic follow-up studies and flat plate abdominal radiographs had been obtained for all patients. The three different anesthetic techniques used were high-frequency jet ventilation (HFJV) in 73 patients, low-volume conventional mechanical ventilation (LVCMV) in 30 patients, and epidural anesthesia with iv sedation in 186 patients.

High-frequency Jet Ventilation. Our method of general anesthesia with HFJV was virtually the same as that described by Carlson *et al.*[2] After induction of anesthesia and endotracheal intubation with thiopental, fentanyl, and succinylcholine iv, anesthesia was maintained with 60% nitrous oxide. This was supplemented with an iv fentanyl infusion at 2–2.8 $\mu g \cdot kg^{-1} \cdot h^{-1}$ and titrated to maintain a steady heart rate and arterial blood pressure. HFJV, using a 14-gauge jet injector inserted in a standard endotracheal tube, was adjusted for a frequency of 100 cycles/min, an inspiratory time of 20%, and a driving pressure to ensure end-tidal P_{CO_2} of approximately 35 mmHg. Oxygenation was monitored with a pulse oximeter, and ventilation was monitored by switching back to the conventional anesthesia circuit and obtaining an end-tidal P_{CO_2} level with a single breath of 15 ml/kg.[3]

Low-volume Conventional Mechanical Ventilation. The anesthetics used were the same as described for HFJV with two exceptions: enflurane (0.3–1%) was added to the inspired gas mixture, and an iv fentanyl infusion was not used. The mechanical respirator was set to deliver a tidal volume of 300 ml. The rate of ventilation was adjusted to between 15 breaths/min and 25 breaths/min to keep the end-tidal P_{CO_2} level between 24 mmHg and 34 mmHg.

Epidural Anesthesia. An epidural block was performed using the loss of resistance technique with a Tuohy Weiss needle, and a catheter was left *in situ.* In all cases, a sufficient volume of lidocaine 1.5% or 2% with 1:200,000 epinephrine was used to obtain a T4 sensory level. All patients were given iv sedation with diazepam 2.5–10.0 mg iv, fentanyl 0.05–0.15 mg iv, or combinations sufficient for the patient to be well sedated in the lithotripter bath.

Thirteen anesthesiologists and five urologists rotate through our lithotripter unit in a random sequence. Choice of anesthetic technique was a matter of personal preference by the anesthesiologist, and was made without prior knowledge of stone burden or location of the stone. The group of patients receiving HFJV and LVCMV was made up of those considered psychologically unsuitable for epidural anesthesia, those with anatomic contraindications (*e.g.*, hemiplegia or spina bifida), and those in whom epidural anesthesia could not be established.

Stone Burden, Vertical Stone Movement, and Stone Composition. Stone burden is defined as the sum of the largest linear lengths in millimeters of all stones treated in each patient, and was measured and recorded by the supervising urologist based on the pretreatment plain film of the abdomen.

The range of vertical stone movement with quiet respiration was measured on the fluoroscopic screen in 21 patients receiving epidural anesthesia and compared to

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those results with HFJV and LVCMV reported by others in the literature.

Stone composition was determined by straining of the urine and chemical analysis of the fragments.

Statistical Methods. A computerized prospective protocol provided follow-up data on all patients. Statistical significance of data was analyzed by chi-square test or Miettinen's modification of the Fisher exact test. Normality of distribution of the clinical parameters of age, sex, stone burden, stone location, and components of stone composition was analyzed by Kalmogorov-Smirnov test using the SPSS^x statistical package in an IBM® 3081 computer. Depending on distribution normality, the significance of differences of parameters between groups receiving various anesthetics was analyzed by Kruskal-Wallis test or chi-square test using the statistical package.

Results

There were no significant differences at the $P = 0.05$ level between patients in the three anesthetic groups for the clinical parameters of age, sex, stone burden, stone location, and components of stone composition.

Fluoroscopic measurement of vertical stone movement with quiet respiration in 21 patients receiving epidural anesthesia showed a value of 20.1 ± 8.5 mm (mean ± SD). Correction for a twofold magnification effect of fluoroscopic imaging indicated a corrected anatomic vertical stone movement of 10.0 ± 4.2 mm (mean ± SD) with a range of 5–21 mm.

The accuracy of halving stone movement as measured on the fluoroscope monitor was verified. The image intensifier head was placed in each of the three positions used for patients of small, average, and large size. A metal object of known diameter was placed at the second focus of the shock wave (f_2) in each position and the images measured. The magnification factors were ×1.8, ×2.0, and ×2.2, respectively.

For the epidural group, the stone burden (mean ± SD) was 17.6 ± 14 mm (range 2–104), for the HFJV

TABLE 1. Success of ESWL Treatment for Nephrolithiasis According to Method of Anesthesia Used

Method	Successes (n)	Successes (%)	Failures (n)
High-frequency jet ventilation	49	67.12	24
Low-volume conventional mechanical ventilation	19	63.33	11
Epidural	139	74.73	47
Total	207		82

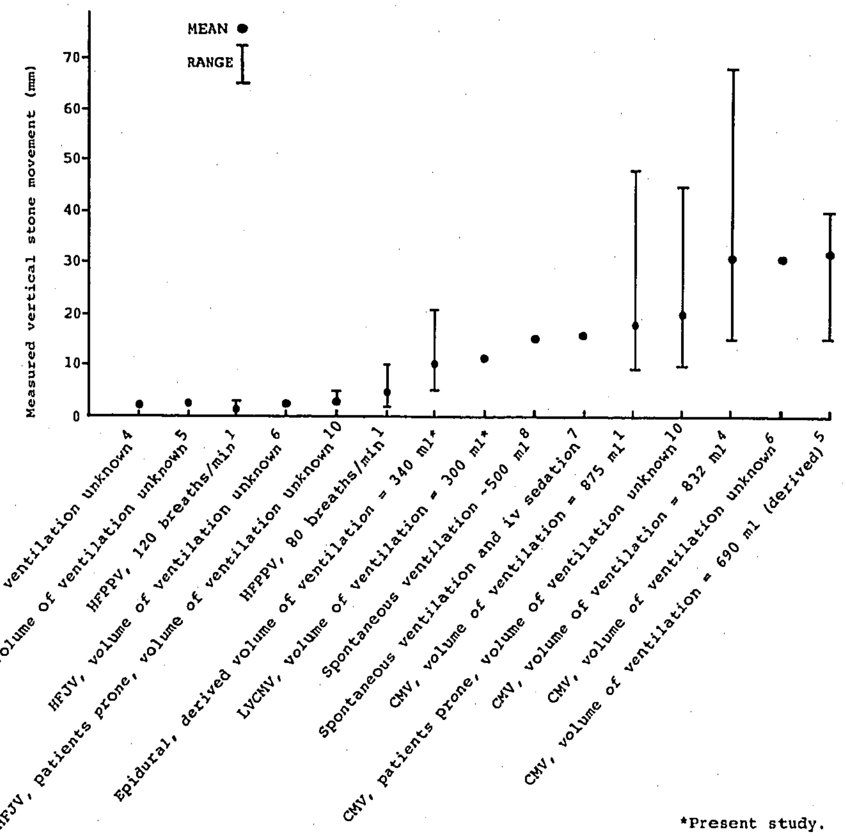

FIG. 1. Stone movement during ESWL related to method of ventilation or tidal volume of ventilation (mean of patients studied). CMV = conventional mechanical ventilation; HFPPV = high frequency positive pressure ventilation. The numbers after each type of ventilation refer to the specific reference.

group 19.9 ± 17 mm (range 4–80), and for the LVCMV group 22.4 ± 19 mm (range 5–82). As indicated in Materials and Methods, the HFJV and LVCMV data were derived from the literature.

Flat plate radiography of the abdomen was performed 6 weeks after ESWL. If no fragments were seen or if they were <5 mm in diameter, the result was considered successful. No statistically significant relationship was determined between the success rate of ESWL and the method of anesthesia used (table 1).

Discussion

The correlation of stone movement with tidal volume of ventilation is central to any discussion of anesthetic technique in relation to the success of ESWL. Carlson *et al.*[4] measured stone movement during both conventional mechanical ventilation (CMV) and HFJV in 30 patients. They found that, during CMV with a tidal volume of 12–15 ml/kg (mean 832 ml, range 600–1200 ml), the mean vertical stone movement measured fluoroscopically was 31 mm (range 15–68 mm). The tidal volume during HFJV could not be measured, but the mean stone movement was 2.2 mm. Schulte am Esch *et al.*[5] studied 155 patients and noted that, when CMV was used, the mean peak airway pressure was 20 cm H_2O. This is close to the mean peak airway pressure in the patients reviewed by Carlson *et al.*,[4] and, therefore, it is not unreasonable to derive an approximate average tidal volume of 690 ml for the group of Schulte am Esch *et al.*[5] At this tidal volume, the authors found a mean stone movement of 32 mm (range 15–40 mm). Similarly, London *et al.*[6] report average stone movement of 2.17 mm during HFJV compared with 30.6 mm during CMV.

In our series of 21 patients with epidural anesthesia and iv sedation, the mean stone excursion with respiration was 10 mm. This figure is intermediate between values with HFJV and with CMV. Drummond *et al.*[7] found that, in a group of 20 patients who had received oral benzodiazepine premedication but no anesthesia, the mean tidal descent of the dome of the diaphragm was 16 mm during spontaneous breathing. Similarly, Wade and Gilson[8] found that, with a mean tidal volume of 500 ml during normal breathing in the upright position, the dome of the diaphragm moved 15 mm. Our

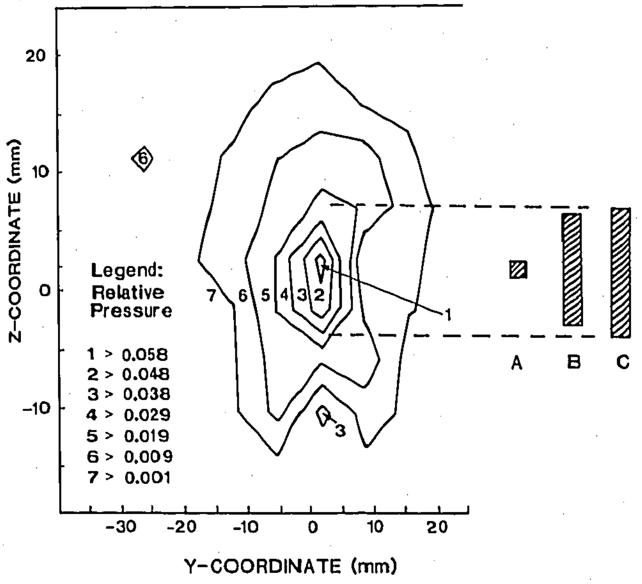

FIG. 2. Contours representing relative pressure isobars on a horizontal plane perpendicular to the axis of the foci (from Hunter *et al.*[10]). According to Hunter *et al.*,[10] the contours have been squeezed artificially along the X-Y axis to conform to SAS graphics scale, or they would have appeared more circular. Three vertical bars A, B, and C, are superimposed to the right using the same scale. A represents mean vertical stone movement during HFJV as derived from values observed by Carlson *et al.*[4] B shows mean vertical stone movement in 21 of our patients who received epidural anesthesia and iv sedation. C represents mean vertical stone in our patients who received LVCMV as derived from values of Carlson *et al.*[4] During CMV, Carlson *et al.*[4] measured mean vertical stone movement of 3.7 mm for each 100 ml of tidal ventilation.

TABLE 2. Number of Shock Waves During ESWL, 1980 to 1987

Year	Author(s)	Patients or Treatments (n)	Shocks (n)
1980	Chaussy *et al.*[12]	21 patients	500–1000
1981	Chaussy *et al.*[13]	72 patients	500–1000
1984	Chaussy *et al.*[14]	945 patients	978 ± 134
1984	Finlayson and Thomas[15]	>3000 treatments*	1000–1500
1985	Schulte am Esch *et al.*[5]	155 patients	1100–2200
1985	Arnold *et al.*[16]	3–12 patients/day	1500–2000
1985	Duvall and Griffith[17]	100 patients	550–1600
1986	Kulb *et al.*[18]	68 patients	Up to 2000
1986	Nisonson *et al.*[19]	226 patients	500–3300
1986	London *et al.*[6]	220 treatments	520–2300
1986	Aeikens *et al.*[20]	8–10 patients/day	300–2600
1986	Perel *et al.*[1]	30 patients	Up to 2000
1987	Roth, unpublished data	~1400 patients	Up to 2400

* Experience at various centers.

patients who had an epidural block and who were also sedated had a measured mean stone movement that was about one-third less than that in the patients of Drummond *et al.*[7] and Wade and Gilson.[8] Arborelius *et al.*‡ found that immersion up to the neck reduced functional residual capacity by 30–36%, which might explain these differences. It should also be noted that Wade and Gilson[8] and Drummond *et al.*[7] were measuring the movement of the dome of the diaphragm, whereas we measured stone movement. The precise correlation between the two has not been determined.

The relationship between tidal volume of ventilation and stone movement in several studies is summarized in figure 1. The vertical bars represent anatomic stone movement, *i.e.*, movement corrected for fluoroscopic magnification.

The investigators[2,4,5] who have related stone movement to the success of ESWL have said, in effect, the less movement the better. However, our study shows that, within certain limits, the amount of movement makes no difference. This observation may be explained by the findings of Hunter *et al.*[10] They mapped the pressure isobars at f_2 in the vicinity of the kidney (fig. 2). These isobars are perpendicular to the direction of the shock wave, and stone movement is approximately parallel to this plane. The "three-dimensional" effects of the shock wave, *i.e.*, the different effects on the front and back surfaces of the stone, are not represented. In figure 2, three vertical bars are superimposed to represent mean stone movement with the three methods of ventilation studied. The vertical bars have the same scale as the pressure isobars, and also represent the direction of stone movement. Mean vertical stone movement is represented for our patients who received HFJV (derived from values observed by Carlson *et al.*[4]), for 21 patients who had epidural anesthesia, and for patients who received LVCMV (derived from values of Carlson *et al.*[4]). Our data suggest, but do not prove, that, as long as vertical stone movement during ESWL stays within the shock-wave relative pressure isobar of >0.029 as defined by Hunter *et al.*,[10] the stone will be subjected to sufficient destructive force. It can be observed that the relative pressure for the isobar that includes area 4 is 50% of that in area 1, which is at f_2 (>0.029:>0.058) (fig. 2). By definition, f_2 is the second focus of the shock wave generated by the spark plug and reflected by the ellipsoid in the lithotripter, and is the point of peak pressure. On the other hand, outside area 4, there is a rapid falloff in relative pressure, *e.g.*, in area 6 relative pressure is only 16% of that in area 1 (>0.009:>0.058). Saunders and Coleman[11] have also described a pressure profile surrounding the major axis of the lithotripter ellipsoid, which decreases centrifugally and is entirely comparable to that described by Hunter *et al.*[10]

Our results and explanations should be interpreted with caution for several reasons. First, our study reviewed clinical outcome in the first 289 patients treated in our lithotripter unit, and so it was retrospective rather than randomized. No attempt was made to match the three patients groups. In fact, it is possible that body habitus, which would affect total lung compliance and excursion of the diaphragm, might have influenced selection of anesthetic technique introducing a bias in the study. Second, we measured stone movement in only 21 of 139 patients who received an epidural anesthetic. Third, the mean stone movement in our patients who received HFJV and LVCMV is derived from the results of other investigators, and do not necessarily apply to our patients.

We did not attempt to study the number of shock waves required for successful ESWL. As pointed out by Perel *et al.*,[1] definitive studies have not yet appeared proving that variations of the number of shock waves required for successful treatment is related to stone movement. Perel *et al.*[1] further note that, since destruction of a stone into fine grains facilitates its excretion, the tendency is to increase the number of shock waves, even when the stone disintegrates relatively early. This observation is supported by the reportedly greater number of shock waves used at present compared with the early days of ESWL (table 2).

In summary, we found no difference in the long-term effectiveness of ESWL in nephrolithiasis using three alternative methods of anesthesia, although each method resulted in a different amount of diaphragmatic excursion and, therefore, vertical stone movement. The explanation for this may be that the effective shock wave isobar accomodates the different ranges of stone movement. ESWL has no accepted end point during therapy, and, therefore, we were unable to study the effect of the number of shock waves on success of treatment.

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Changes in Oxygen Saturation Following General Anesthesia in Children with Upper Respiratory Infection Signs and Symptoms Undergoing Otolaryngological Procedures

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Anesthesiologists frequently face the problem of a child with signs and symptoms of an acute upper respiratory infection (URI) presenting for surgery. The risk of anesthesia and surgery in these patients has not been clearly established. A previous study at our hospital has shown that patients with a history of resolving URI have an increased risk of developing perioperative atelectasis and hypoxia,[1] yet others[2-4] have suggested that anesthesia and surgery in the presence of an uncomplicated URI may have minimal morbidity and may not be contraindicated.

In this study, we prospectively examined the possible association between URI symptoms and systemic arterial oxygen saturation before and following general anesthesia in otherwise healthy children presenting for elective otolaryngological surgery.

MATERIALS AND METHODS

The study was approved by the institutional research committee and parental consent was obtained. Fifty children ranging in age from 1 to 4 yr were studied: 25 without history or signs and symptoms of URI (controls), and 25 with signs and symptoms of URI during

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