Order Number 1333272

Synchronized high frequency jet ventilation during extracorporeal shock wave lithotripsy

Warlick, Kathleen Marie, M.S.

The University of Arizona, 1988

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark _✓_.

1. Glossy photographs or pages _____
2. Colored illustrations, paper or print _____
3. Photographs with dark background _✓_
4. Illustrations are poor copy _____
5. Pages with black marks, not original copy _____
6. Print shows through as there is text on both sides of page _____
7. Indistinct, broken or small print on several pages _✓_
8. Print exceeds margin requirements _____
9. Tightly bound copy with print lost in spine _____
10. Computer printout pages with indistinct print _____
11. Page(s) _____ lacking when material received, and not available from school or author.
12. Page(s) _____ seem to be missing in numbering only as text follows.
13. Two pages numbered _____. Text follows.
14. Curling and wrinkled pages _____
15. Dissertation contains pages with print at a slant, filmed as received _✓_
16. Other _____

SYNCHRONIZED HIGH FREQUENCY JET VENTILATION DURING EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY

by

Kathleen Marie Warlick

A Thesis Submitted to the Faculty of the

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 8 8

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Kathleen Marie Warlick

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Kenneth C. Mylrea
Kenneth C. Mylrea
Professor of Electrical and Computer Engineering

Apr 29 1988
Date

ACKNOWLEDGEMENTS

I wish to thank Dr. Randy Cork and Dr. Kenneth Mylrea for their help, guidance and support they have given me throughout the duration of this projet. I wish to thank my fellow students, especially Sarah Samoy, for their help and encouragement. I would especially like to thank Rose Kaczanowski for her special contributions to the success of this project. Finally, I wish to thank my husband and my parents for their love, understanding and support throughout my career endeavors.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

Physiologic and Extracorporeal Shock Wave Lithotripsy (ESWL) data were collected before, during and after ESWL from four patient groups employing different anesthetic techniques (epidural anesthesia, general anesthesia with low-volume conventional mechanical ventilation or with unsynchronized high frequency jet ventilation (HFJV) or with HFJV synchronized to the heart rate). The primary goal was to determine if synchronized HFJV had any beneficial effects. A synchronization unit was fabricated that triggered one HFJV breath, per heart beat, delivered 30 milliseconds after the shock wave. This allowed only expiratory motion during shock wave administration. Results were analyzed using one-way analysis of variance, Students t-tests and chi-square tests with significance at $p < 0.05$. Results showed that renal stone excursion was significantly less in HFJV groups and that significantly more patients required re-treatment in non-HFJV groups. No results indicated that synchronizing HFJV had any further benefits than unsynchronized HFJV.

Synchronized High Frequency Jet Ventilation During Extracorporeal Shock Wave Lithotripsy

Chapter 1

INTRODUCTION

High Frequency Jet Ventilation (HFJV) has been shown to minimize renal stone movement, caused by diaphragmatic movement during both spontaneous and conventional mechanical ventilation (CMV), during the procedure of Extra Corporeal Shock Wave Lithotripsy (ESWL). The purpose of this thesis was to determine whether using HFJV synchronized to the human cardiac cycle further minimizes renal stone movement, and if so, whether or not this reduction in stone movement actually improves the current procedure of ESWL. Currently, the two most widely used methods of anesthesia for ESWL are the use of epidurals and general anesthesia with low-volume conventional mechanical ventilation (LVCMV). Previous studies have shown that the main advantage of epidurals, with spontaneous respiration, has been patient cooperation due to the awake state of the patient. However, these same studies have shown general anesthesia, with LVCMV, having an advantage of minimizing diaphragmatic movement, thus minimizing renal excursion and stone movement. Therefore, no studies have proven any significant advantages of one method over the other and the use of each is currently popular. Since HFJV requires the use of general anesthesia, this study had a secondary purpose to determine whether significant advantages exist with general anesthesia in ESWL. This study was completed at the University Medical Center in Tucson, Arizona for the Department of Anesthesiology.

ESWL is a noninvasive means of disintegrating upper urinary tract calculi. The theory and development of ESWL came about when Dornier [Dornier Medical Systems, Munich] engineers investigated the presence of pitting that was observed on aircrafts after high-speed flight. Studies that were then conducted showed that shock waves were generated as a result of the collision between small hard particles or raindrops present in the atmosphere and the shell of the aircraft at supersonic speeds. These shock waves were found to have caused damage to the aircraft in areas distal to the site of the original collision. This phenomena was based on the theory that a tensile force is created in the solid when shock waves traverse the interface of materials with different acoustical properties. As a result, a government-funded project was begun by Dornier in 1974 to investigate the possibility of treating kidney stones with shock waves. Dornier was successful in their endeavor and found that in lithotripsy the shock wave travels harmlessly through soft tissue and has a destructive effect when it reaches the denser composition of the stone. The first patient was treated successfully at the University of Munich in 1980.[1]

There are five components to the modern day lithotripter. First, there is a high voltage generator that is responsible for creating a spark at an underwater electrode gap. This discharge produces the shock wave with enough energy to have an appropriate impact on the designated stone. Another component is a semi-ellipsoid reflector which functions to focus the generated shock wave to the focal target point of the stone. A dual X-ray system exists in order to position the stone for optimum destruction and also to check the progress of treatment. The last two components consist of a chairlike patient support system that both holds and positions the patient and a tub of degassed, demineralized water. The water is necessary to provide a medium in which the shock wave can travel from its origination to the kidney without causing any harmful effects. There are now lithotripter units that have eliminated the need for the tub of water using water cushions covering the ellipsoidal reflector and X-ray tubes in order to couple the shock waves to the body.[2]

The following events occur during a typical ESWL treatment. First, the patient is anesthetized, placed in a semi-fowler position, and secured into the patient support frame. The frame is lowered into the tub of water and the patient is positioned in order that the shock waves will be targeted to the stone, by means of the semi-ellipsoidal reflector, for optimum stone breakage. The shock waves are then produced by high-voltage discharges at the underwater electrode and are also synchronized to the cardiac cycle in order to prevent dangerous arrythmias that may occur from the action of the shock waves. Treatment by the shock waves is frequently interrupted in order to visualize, by fluoroscopy, the progress of stone disintegration. Treatment is completed when the physician determines that the kidney stones are reduced to passable size. The patient is then transported to the recovery room and is usually released later that same day.

ESWL, in the short time it has been approved for use in this country by the FDA, has been shown to be the treatment of choice for kidney stones. It has been estimated that 2% to 3% of the population, or approximately 874,000 patients per year are diagnosed with some type of urinary stone,[3] and that currently 80% to 90% of these patients can be treated successfully by lithotripsy.[4] Currently, 95% of the patients treated with ESWL have been stone-free after one treatment and also seem to have suffered few side effects.[5]

ESWL can also become cost efficient for both hospitals and patients. The cost of purchasing and maintaining a lithotripter is high. However, these costs can be spread over a large number of individuals and the electrodes are cheaper if bought in large volumes.[3] Another significant benefit in both cost and health, is the much shorter hospitalization time for patients receiving ESWL versus surgery. Surgery for kidney stones usually requires hospital stays of up to seven days. However, the benefits of ESWL decline if multiple treatments are necessary for the same kidney stone.

High Frequency Jet Ventilation (HFJV) is a means of ventilation which involves a smaller tidal volume (estimated to be approximately that of the physiologic dead space of the lungs, 50-150 ml) that is forced into the lungs by means of short pulses of gas at frequencies of 60 to 900 pulses per minute. Expiration is usually passive. The mechanics of HFJV is still not clearly understood, but is thought to mainly occur by diffusion rather than the bulk movement of air through the respiratory passageways. Rates as high as 600 pulses/min have been used in studies involving dogs, but adverse circulatory effects occurred in these dogs above 400 pulses/min.[6] In the United States, the FDA has approved HFJV rates, in humans, up to 150 breaths/min.

HFJV was introduced by Sanders in 1967 as a means of ventilatory support during bronchoscopy.[6] For 10 years its use was limited to bronchoscopy, until Smith and Klain suggested that HFJV could be successfully used in CPR.[6] Several other researchers evaluated this new method of ventilation and its use was researched in various surgeries and respiratory ailments where conventional mechanical ventilation (CMV) appeared to aggravate existing conditions.[6] However, this research has not shown, except in limited cases, that using HFJV is an improvement over existing methods either in respiratory ailments or surgeries. As a result, its popularity, has declined and it is routinely used only for diagnostic or therapuetic laryngotracheal surgery.[7] Several areas of HFJV use continue to appear promising, but thus far not enough research has been completed to prove enhancement by HFJV. Areas in which HFJV may prove beneficial are in treating patients with open bronchopleural cutaneous fistulas, acute respiratory distress syndrome in neonates (RDS) or adults (ARDS), and during thoracic, abdominal and neurological surgical procedures where it is important to have reduction of lung movement.[7] Also, its use in ESWL is seen as promising and is a major component of this thesis.

The idea of using HFJV during ESWL came into focus due to the observation that HFJV results in less movement of the thoracic area, hence less movement of the entire body, than either CMV or spontaneous ventilation. Therefore, theoretically, more shock waves will hit the optimal target point of the stone which, in turn, would decrease both treatment time and complications (due to shock waves missing the stone and hitting adjacent organs). Current studies have supported this observation by showing that HFJV significantly reduces stone movement. In one study, the vertical displacement of the stone with CMV was reported to have a mean of 32 mm versus mean stone movement of 2 to 3 mm using HFJV.[8] Another study, using high-frequency positive pressure ventilation (HFPPV) at rates of 80 breaths/min, found vertical mean stone movements of 17.8 ± 8.8 mm using CMV whereas mean stone movements were only 4.7 ± 1.8 mm during HFPPV.[9] One other study has gone a step further by reporting results that show a significant reduction in the number of applied shock waves and electrodes in the HFJV-treated group versus the CMV-treated groups.[10]

Problems in using HFJV during ESWL have been reported also. One study, in particular, reports that out of 407 cases in which HFJV was used as the mode of ventilation during ESWL, 8 patients developed bronchoconstriction and wheezing severe enough to necessitate discontinuing HFJV as the mode of ventilatory support.[11] None of the 8 had abnormal preoperative chest X-rays or history of asthma. These same researchers found that in the next 200 patients receiving HFJV with isoflurane in addition to nitrous oxide and fentanyl, no problems occurred with those patients that had not wheezed before the induction of anesthesia.[11]

There still has not been enough research to determine whether or not HFJV with general anesthesia should become the anesthetic method of choice during ESWL. Except for the study mentioned earlier that took into account the number of applied shock waves used during ESWL treatment, investigations have been limited in scope and in their observations of clinical outcome. Therefore, the goal of this thesis is to show, by looking at several important areas of data, whether or not HFJV improves the current procedure of ESWL. These areas include the duration of ESWL and other treatment time periods, the frequency and kilovoltage of the applied shock waves, the occurance of complications and results of follow-up Kidney, Ureter and Bladder (KUB) exams that determine actual stone disintegration. Also, we will evaluate further whether or not synchronizing HFJV to the cardiac cycle provides an additional benefit.

Chapter 2

MATERIALS AND METHODS

The study population consisted of 34 patients undergoing ESWL at the University Medical Center in Tucson, Arizona. The 23 men and 11 women had a mean age of 50.2 years and a mean weight of 76.6 kilograms. The ASA physical status of these participants was classified as 15 ASA I, 17 ASA II, and 2 ASA III. These patients were randomized into four groups. Group 1 consisted of 10 patients who received epidural anesthesia with spontaneous respiration. Group 2 consisted of 8 patients who received general anesthesia with LVCMV (5-8 ml/kg tidal volume). Groups 3 and 4 consisted of 16 patients who received general anesthesia with HFJV. Group 3 consisted of 8 patients who received HFJV synchronized to their heart rate and group 4 consisted of 8 patients who received HFJV at a standard rate of 150 breaths/minute. HFJV was only used while the subject was in the tub of water during ESWL. The study was approved by the Arizona Health Sciences Human Subjects Commitee and written informed consent was obtained in all cases.

2.1 Anesthesia

General anesthesia was induced with thiopental 1-2 mg IV, sufentanil 0.5 ug/kg IV and vecuronium 0.1 mg/kg IV. Maintenance was with a sufentanil drip beginning at 0.5 ug/kg/min and titrated downward as tolerated and 60% N_2O/40% O_2. Patients receiving LVCMV were ventilated at rates of 15 to 20 breaths/minute and tidal volumes of 5 to 8 ml/kg. Patients receiving HFJV were first ventilated with CMV at rates of 15 to 20 breaths/minute and tidal volumes of 9 to 13 ml/kg and then placed on HFJV once they were positioned in the tub of water. The unsynchronized rate for HFJV was 150 breaths/minute with % inspiratory time at 30% of the cycle. Driving pressure was adjusted to maintain the pulse oximeter reading > 95% and end tital CO_2 at < 40 mmHg. The synchronized HFJV was different in only that the rate was equal to the heart rate.

Epidural anesthesia was performed with the loss-of-resistance technique using a Tuohy needle and catheter left in situ. Initial anesthetic was 20 to 30 ml of 2% lidocaine with epinephrine 1:200,000. Anesthetic levels from T_3 to T_7 were obtained. Anesthetic was supplemented with 5 to 10 ml as necessary. Sedation was with 4 to 8 mg midazolam IV and/or 100 to 200 ug fentanyl IV as necessary.

2.2 Physiologic and ESWL Variables

Readings of heart rate, systolic, diastolic, and mean blood pressures and respiratory rate were recorded on all subjects pre-operatively, during the procedure, and at admission and discharge from the recovery room. Additionally, nasopharangeal temperature and O_2 saturation [Nellcor Hayward,CA] were recorded at specific times during the procedure and during cystoscopy if it was performed. For subjects receiving general anesthesia, including both LVCMV and HFJV groups, the airway resistance, pulmonary compliance, and work of inspiration of the lungs, ventilator rate, tidal volume, and end tital CO_2 (Et CO_2) were recorded during the procedure. Resistance, compliance and work of inspiration of the lungs, ventilator rate, and tidal volume were recorded from measurements obtained by the Critikon Anesthesia Respiratory Monitor (Model 8510) [Critikon, Inc. Tampa, Florida]. Et CO_2 was measured by the Datex CO_2 Monitor [Puritan-Bennett Los Angelos, CA]. When obtaining these values during cases where HFJV was used, HFJV was discontinued and subjects were placed back on LVCMV for the few minutes (or seconds for Et CO_2 readings), required in order to obtain accurate readings. HFJV rate, % inspiratory time, driving pressure, and baseline, mean and peak airway pressures were recorded on subjects in the HFJV groups. These variables were obtained from either operator controlled settings or by measurements obtained by the Healthdyne (Model 300) HFJV [Healthdyne Marietta, GA].

Data were collected at the following specific times:

(1) Preoperatively [BSLN];

(2) Two to three minutes after induction or epidural placement [IND];

(3) Two to three minutes after intubation (except for the epidural group) [INT];

(4) During cystoscopy (if performed) [CYSTO];

(5) Two to three minutes after immersion into the tub of water [IMM];

(6) After 200 hundred shocks were delivered to the subject [ESWL];

(7) Two to three minutes after the completion of ESWL, but while the subject was still in the tub [IN TUB];

(8) Two to three minutes after the subject had been taken out of the tub [OUT TUB];

(9) At the time of extubation (except for the epidural group) [EXT];

(10) Upon admission to the recovery room [R-ADM];

(11) Upon discharge from the recovery room [R-DC].

The following information was also obtained:

(1) Designation as to which kidney was treated (left, right, or bilateral);

(2) Total time the patient was exposed to radiation in minutes (X-ray time);

(3) Temperature of the water in the tub in degrees Celsius (water temperature);

(4) Evaluation, immediately post-ESWL by x-ray, that determined whether or not the treated stone appeared disintegrated;

(5) Excursion of the treated stone(s) along the verticle axis was recorded in millimeters. This measurement was performed by metric ruler placed on the

fluoroscopy screen after 200 shocks were delivered during the mode of ventilation used;

(6) Total amount of power used during the treatment was calculated. In ESWL, this term is defined as the number of shock waves delivered integrated over the kilovoltage used for each shock wave;

(7) Whether or not the subject experienced pain while in the recovery room and how much Demerol (meperidine hydrochloride) was given in milligrams;

(8) Follow-up KUB results completed on the subjects 4-7 weeks after treatment that assessed actual stone disintegration and resultant fragment clearance (either "success" or "failure");

(9) Whether complications occurred as a result of the procedure (either "yes" or "no").

The treatment time periods that were calculated included the following:

(1) Transfer time (the time from the completion of ESWL to recovery room admission) [Transfer];

(2) Length of ESWL treatment [ESWL];

(3) Recovery room time [Recovery];

(4) Anesthesia time (the time from induction/epi placement to recovery room admission) [Anesthesia];

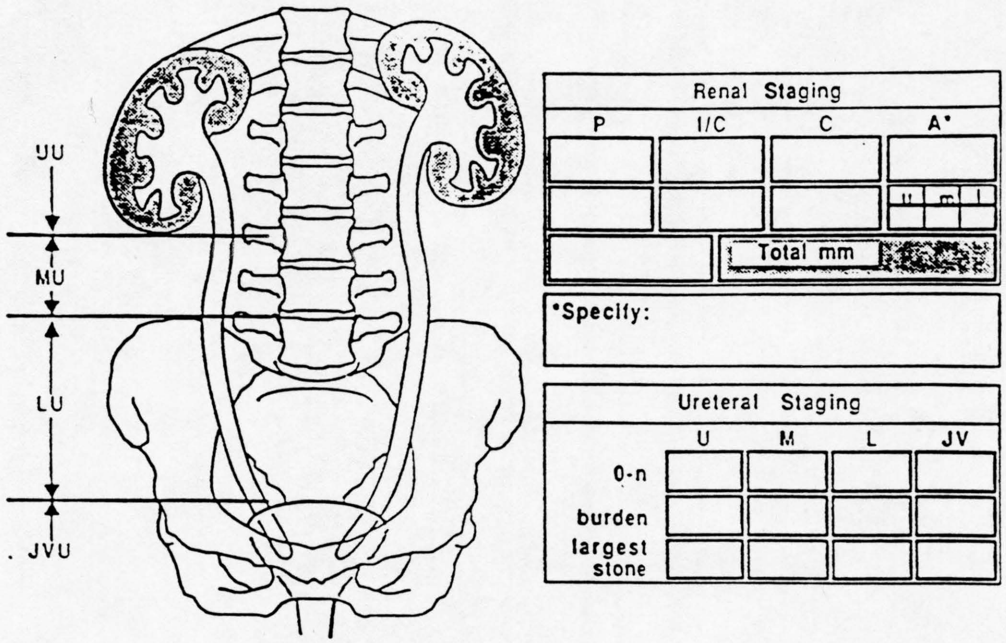
(5) Intubation time (the time from intubation to extubation for non-epidural subjects) [Intubation];

(6) Extubation time (the time from the completion of ESWL to extubation for non-epidural subjects) [Extubation].

2.3 PICA System

Kidney stones were classified pre-treatment by a staging method known as the PICA system.[12] This method divides the renal system into two anatomical regions, the renal and the ureteral regions (Fig. 1). The two anatomical regions are then further subdivided into more descriptive regions which define, in the case of the renal system, whether the designated stones are located within the pelvis (P), if the stones are either branched pyelo-infundibular or infundibular-calyceal or calyceal-calyceal stones (I/C), and if either independent calyceal or independent infundibular stones exist (C). The sub heading (A) records any significant anatomical factors existing which will affect stone treatment. For the ureteral staging system, regions are further broken down into the upper (U), mid (M), lower (L) and juxtavesical (JV) ureter regions. Therefore, stones can be classified before ESWL as to their location which does affect the complexity of treatment.

Another significant feature of the PICA system is its method of recording overall stone burden which also contributes to the level of difficulty in treating the stone(s) by ESWL. First, each stone's length (long axis) is recorded in millimeters in the appropriate column according to the stone's



PICA Schematic for recording stone burden and location: Stones are designated by cavity.

P	=	pelvis
I/C	=	infundibulum = branched stones
		infundibulo-pelvic
		infundibulo-calyceal
		calyceal-calyceal
C	=	calyceal (only) or infundibulum (only)
A	=	anatomical abnormalities
u,m,l	=	upper, mid or lower calyces have stone
UU	=	upper ureter
MU	=	mid ureter
LU	=	lower ureter
JV	=	juxta-vesical ureter

(Courtesy of D.P. Griffith, M.D.)

Fig. 1. PICA System.

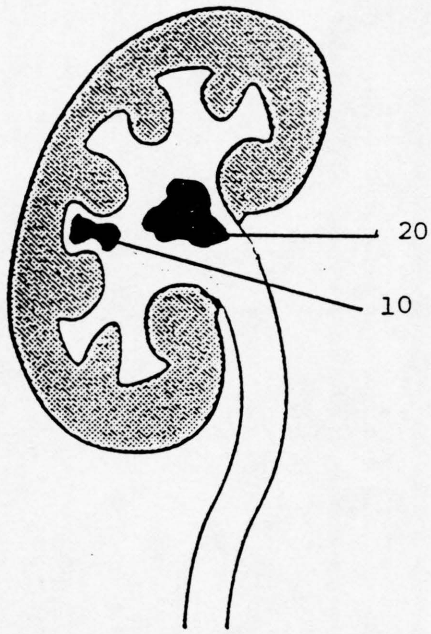
location. These columns are in the second row of the renal scoring box schematic and the middle row of the ureteral scoring box. For example (Fig. 2), if a subject had a pelvic stone 14 by 20 mm and one, non-branched calyceal stone 5 by 10 mm present in the right kidney, the following would be recorded. In the first row of the renal staging box, a 1 would be placed under P and a 1 would be placed under C. The long axis dimension would be recorded in the second row. In this case, 20 would be recorded under P and 10 would be recorded under C. Finally, the total burden would be recorded, in the third row which results in a total of 30 mm. For our purposes in this study, each patient was given a renal or ureteral PICA score (or both). The renal score characterized the sum of the overall burden in mm of the treated stone(s) present in the kidney while the ureteral score characterized the sum of the overall burden in mm of the treated stone(s) present in the ureter.

Another important characteristic of kidney stones which affect treatment by ESWL is stone composition. The limitation of the PICA system is that, unfortunately, it cannot predict the composition or hardness of the treated stone before treatment. Therefore, this aspect of stone classification is not a component of this staging system.

By using the PICA burden scores for each subject it can be shown, before treatment, that no significant differences occurred between study groups as to the degree of difficulty in treating

Renal Staging			
P	I/C	C	A*
1		1	
20		10	u / m / l: X (m)
30	Total mm		

*Specify:



Ureteral Staging	U	M	L	JV
0-n				
burden				
largest stone				

(Courtesy of D.P. Griffith, M.D.)

Fig. 2. PICA System Example.

the stones by ESWL. This is important in order to show that the study population was homogeneous between groups.

Results were analyzed statistically by using SPSSX programs on the Digital Vax computer. The statistical methods used were oneway analysis of variance for comparing data among more than two groups, Student's t-tests for grouped and paired data, and chi-square analysis for categorical data. The following results consist of findings among the four study groups with significance defined as $p < 0.05$

2.4 Synchronization Unit

A synchronization unit was designed and built in order to synchronize the HFJV pulses to the heart rate. It did this from information obtained by the Datascope EKG monitor (Model 2002A). This unit was responsible for allowing the subject one breath (per the HFJV) every QRS segment and controlling the % inspiratory time of the breath. The breath was delivered approximately 50 milliseconds after the peak of the R wave was detected since the Dornier Lithotripter delivers a shock approximately 20 milliseconds after the R wave peak. Therefore, only passive expiratory movement should occur during shock wave administration.

The synchronization unit consisted of two stages (Fig. 3). The first stage was responsible for the detection and transformation of the QRS segment into a square pulse (Fig. 4) and the second stage was responsible of the precise timing and duration of the delivered breath from the HFJV. The input to this stage was from the analog real time EKG signal of the Datascope EKG monitor. The input voltage was the standard 1 mV for EKG signals. The signal was first filtered in order to both rid the signal of the low frequency components (i.e. P wave and T wave) and to decrease 60 Hertz noise that may have been riding on the original signal. This was accomplished by using a fourth order, bandpass Butterworth filter. The transformed signal,

QRS Detector and Timing Circuit

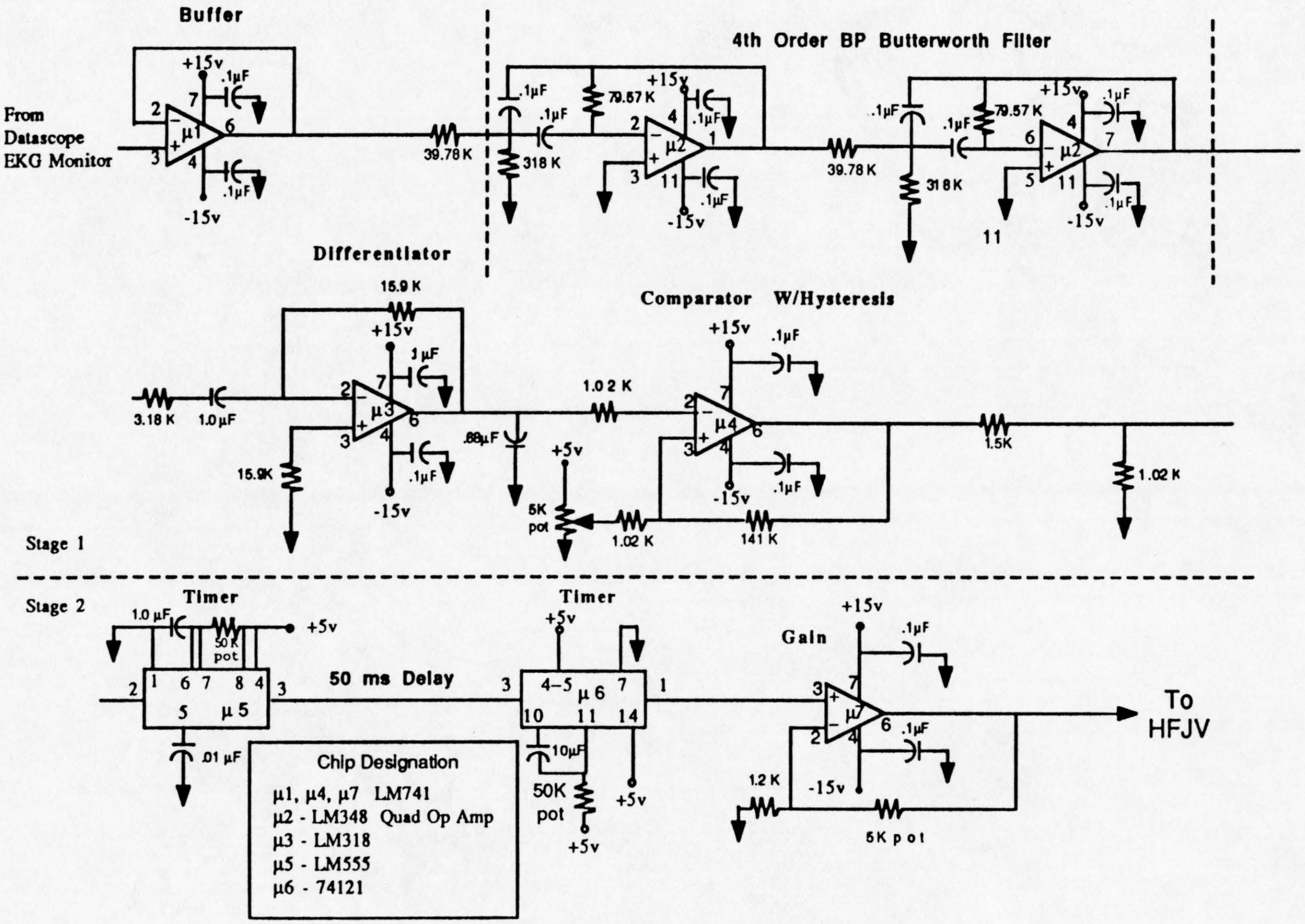


Fig. 3. Synchronization Unit.

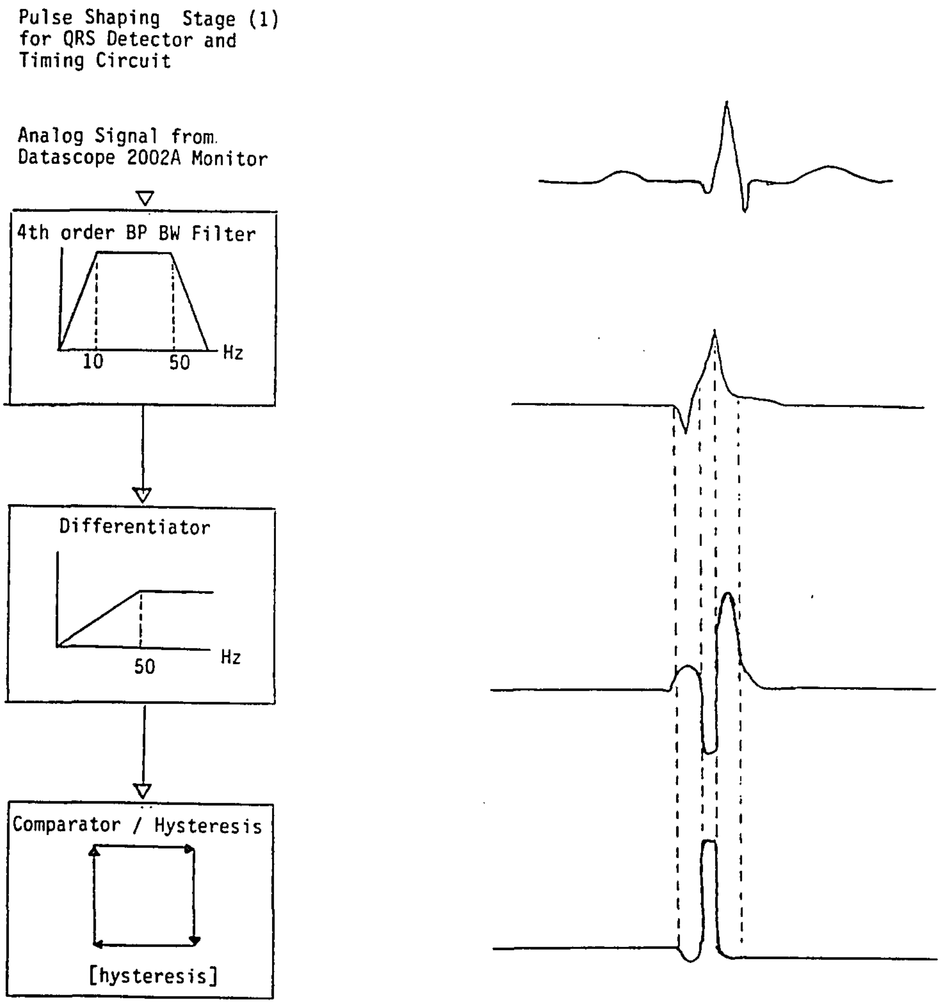


Fig. 4. First Stage of Synchronization Unit.

consisting only of the R wave, was then differentiated in order to obtain a signal which would more resemble a square pulse. Again, only the R wave was differentiated and the frequency response components of the differentiator were selected in a way that assured that this was accomplished (Time constants: $\tau_1 = 1.59 \times 10^{-2}$, $\tau_2 = 3.2 \times 10^{-3}$). The differentiated signal became the input to the last component of the first stage which was a comparator with hysteresis. The reference voltage was made adjustable with a range from 0 to 5 volts and made it possible to set the reference voltage low enough in case nonstandard EKG voltages were encountered, but always high enough to avoid the possibility of superimposed noise from triggering the comparator. By using hysteresis, the output snapped between its two logic states instantaneously which was necessary for the required precise timing of the circuit. The output of the first stage now resembled a square pulse.

The timing of the circuit was deemed very important since it involved the theory upon which this thesis was based. The first component of this stage consisted of a LM555 Timer. The timer was set to operate in its monostable mode and was triggered on the falling edge of the input waveform, the square pulse. The output from the timer was set to remain high for 50 milliseconds before resetting to its previous low state (Fig. 5). The output from the timer became the input to the second component which was a Monostable Multivibrator with Schmitt-Trigger inputs (SN74121).

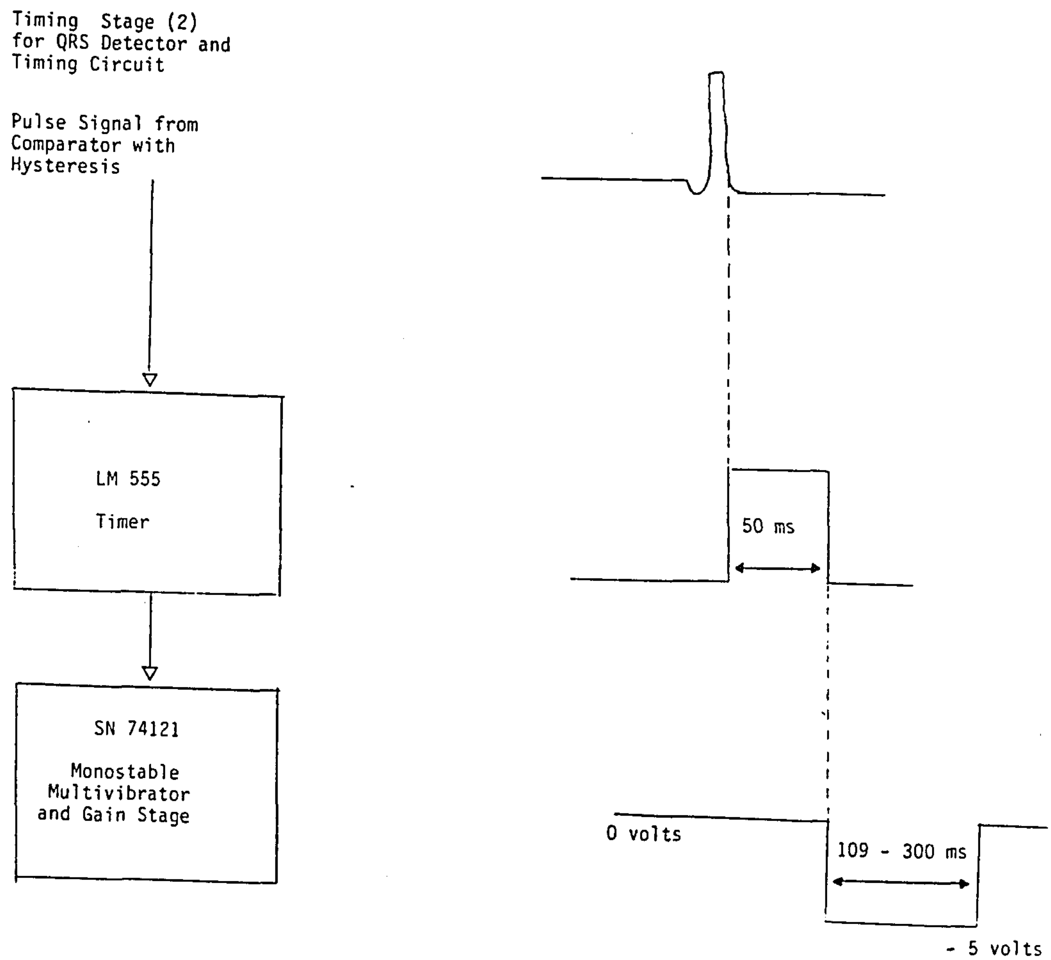


Fig. 5. Second Stage of Synchronization Unit.

The function of the multivibrator was to control the % inspiratory time of the delivered breath and was also triggered on the falling edge of the input waveform, the 50 millisecond square pulse. The % inspiratory time was adjustable by means of 10-turn 50K potentiometer which varied the pulse length of the output, from the multivibrator, from 109 to 300 milliseconds. A constant % inspiratory time of 30% was achieved by constantly varying the pulse length as the subject's heart rate varied. The required input to the Healthdyne HFJV must switch from 0 volts to -5 volts in order to trigger a breath. Therefore, the inverting output of the multivibrator was used and, as a last component, a non-inverting op-amp was used in order to supply the needed gain. The output of this circuit performed as designed and was able to trigger one breath, from the HFJV, for every QRS segment encountered.

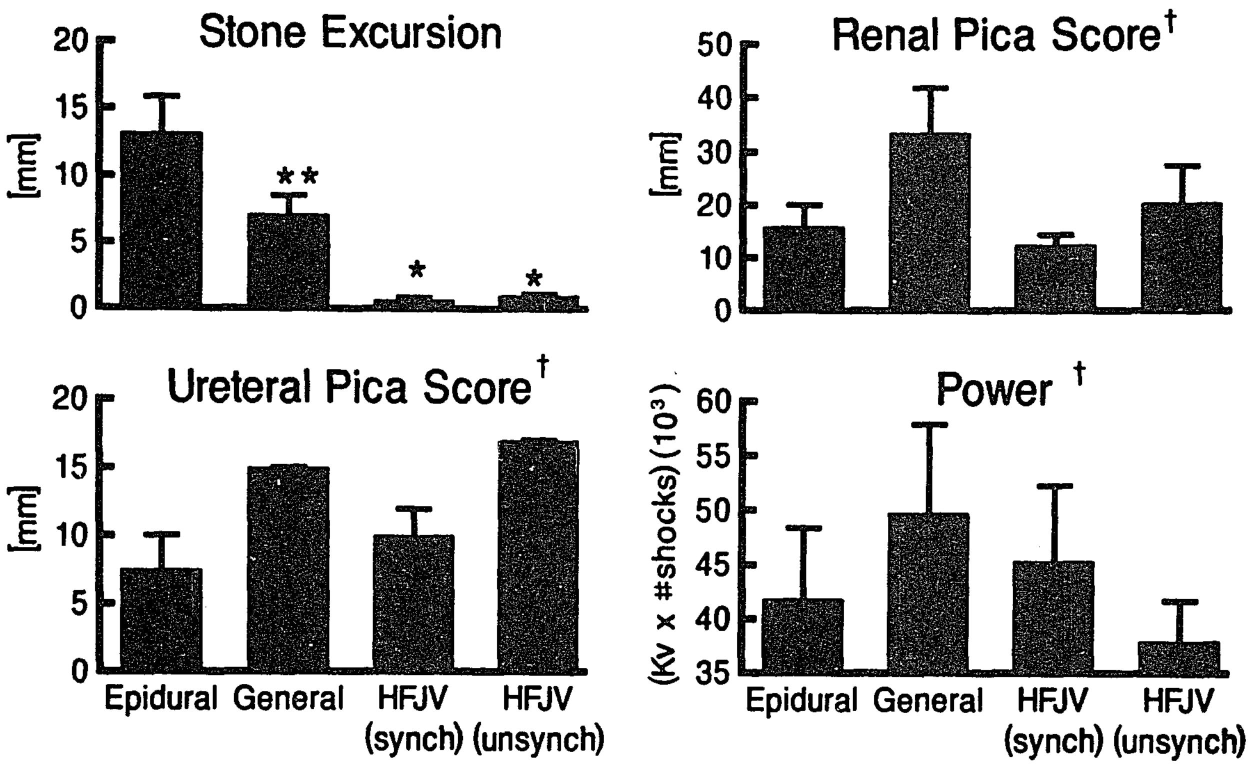
Chapter 3

RESULTS

Results can be divided into three groups. Figs. 6 through 9 show results of renal stone excursion, PICA scores, power results, x-ray time and length of ESWL results among groups specifying kidney designation, treatment related times and HFJV variables. Figs. 10 through 18 show changes in the physiologic variables over the times readings were taken and Table 2 shows follow-up KUB exam and complication results.

Fig. 6 shows that mean stone excursion was significantly lower for both HFJV groups and significantly higher in subjects receiving epidurals than those receiving general anesthesia. However, there were no significant differences noted between the two HFJV groups. Mean stone excursion was 13.2 $\pm$ 2.7 mm with epidural anesthesia, 7.1 $\pm$ 1.4 mm for general anesthesia with LVCMV, 0.7 $\pm$ 0.2 mm for general anesthesia with HFJV(synch), and 1.0 $\pm$ 0.2 mm for general anesthesia with HFJV(unsynch). PICA scores and total power results proved insignificant among the four study groups.

The results of the length of ESWL and the total x-ray time according to kidney designation are shown in Fig. 7. Both mean values were significantly longer in subjects being treated for bilateral stones [x-ray time (4.6 $\pm$ 0.8 min), ESWL time (79.2 $\pm$ 6.6 min)] than both left stone subjects [x-ray time (2.6 $\pm$ 0.4

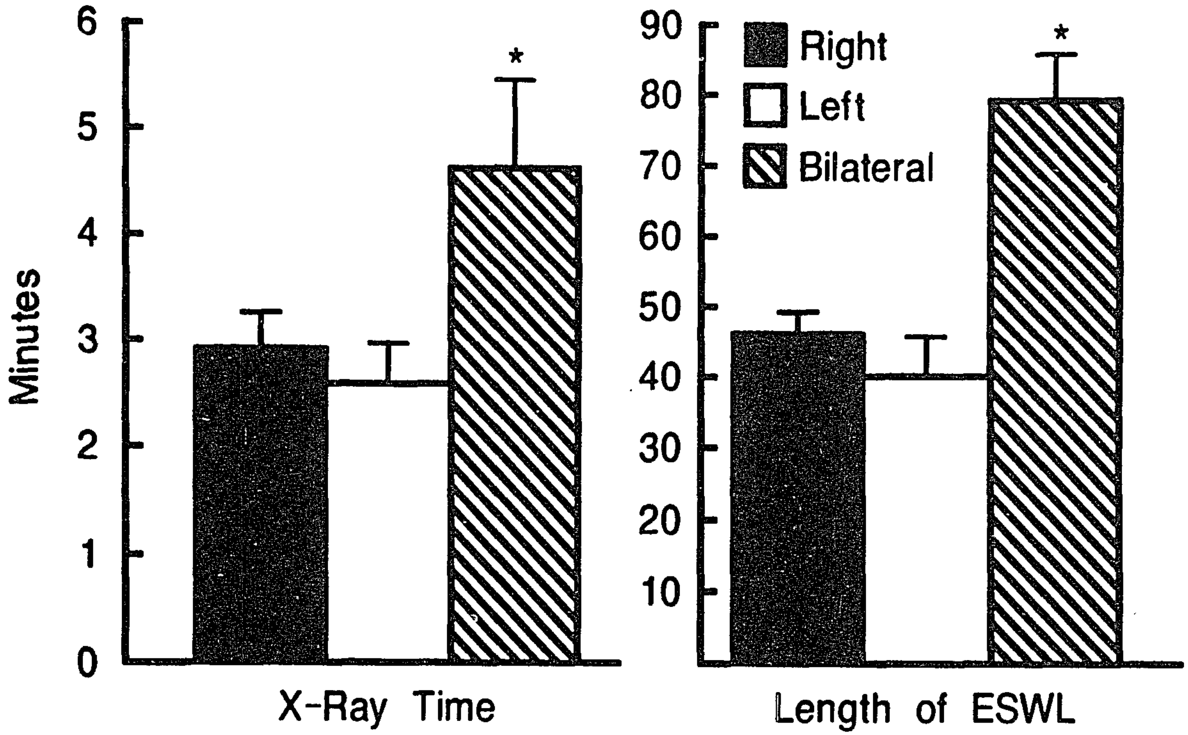


* HFJV groups significantly different from non-HFJV groups at $p<0.05$

** General Group significantly different from Epidural Group at $p<0.05$

† No significance detected at $p<0.05$

Fig. 6. Mean Stone Excursion, Renal PICA Score, Ureteral PICA Score, and Power



* Bilateral stone subjects significantly different from both right and left stone patients at $p<0.05$

Fig. 7. Length of ESWL and Total X-ray Time

Table 1: Abbreviations for times in Figs. 8 and 10 - 18

Abbreviations (Figs. 10 - 18)

BSLN: Preoperative

IND: Two to three minutes after induction or epidural placement

INT: Two to three minutes after intubation

CYSTO: During cystoscopy

IMM: Two to three minutes after immersion into the tub of water

ESWL: After 200 shocks were delivered to the subject

IN TUB: Two to three minutes after the completion of ESWL, but while the subject was still in the tub

OUT TUB: Two to three minutes after the subject had been taken out of the tub

EXT: At the time of extubation

R-ADM: Upon admission to the recovery room

R-DC: Upon discharge from the recovery room

Time periods (Fig. 8)

Transfer: Time from completion of ESWL to recovery room admission

Intubation: Time from intubation to extubation

Extubation: Time from completion of ESWL to extubation

ESWL: The length of ESWL treatment

Recovery: Time in the recovery room

Anesthesia: Time from induction/epi placement to recovery room admission min), ESWL time (40.1 ± 5.6 min)] and right stone subjects [x-ray time (2.9 ± 0.3 min), ESWL time (46.0 ± 3.3 min)].

Fig. 8 depicts the results of the time intervals that were computed. No significant differences were observed among groups for any of the time intervals.

Fig 9 shows significant differences in respiratory rate, mean airway pressure, and peak airway pressure between the HFJV groups. The respiratory rate was significantly different between the two groups since the HFJV(unsynch) Group had a standard respiratory rate of 150 breaths/min while the HFJV(synch) Group (respiratory rate equal to the heart rate) had a mean of 81 ± 2 breaths/min. Mean airway pressure for the HFJV(synch) Group was 9 ± 0.3 cm H_2O and 7 ± 0.4 cm H_2O for the HFJV(unsynch) Group. Peak airway pressure for the HFJV(synch) Group was 13 ± 0.5 cm H_2O and was 11 ± 0.3 cm H_2O for the HFJV(unsynch) Group.

Fig. 10 shows heart rate values for all four groups at the eleven time periods listed. Significant differences occurred at the times of induction (IND), cyctoscopy (CYSTO), and immersion (IMM). At induction, the Epidural Group mean heart rate (85 ± 4 b/min) was significantly higher than both the General Group (66 ± 4 b/min) and the HFJV(unsynch) Group (70 ± 5 b/min). During cystoscopy, the Epidural Group mean heart rate (84 ± 5 b/min) was significantly higher than both the General Group (61 ± 7 b/min) and the HFJV(unsynch) Group (56 ± 2 b/min). At immersion, the

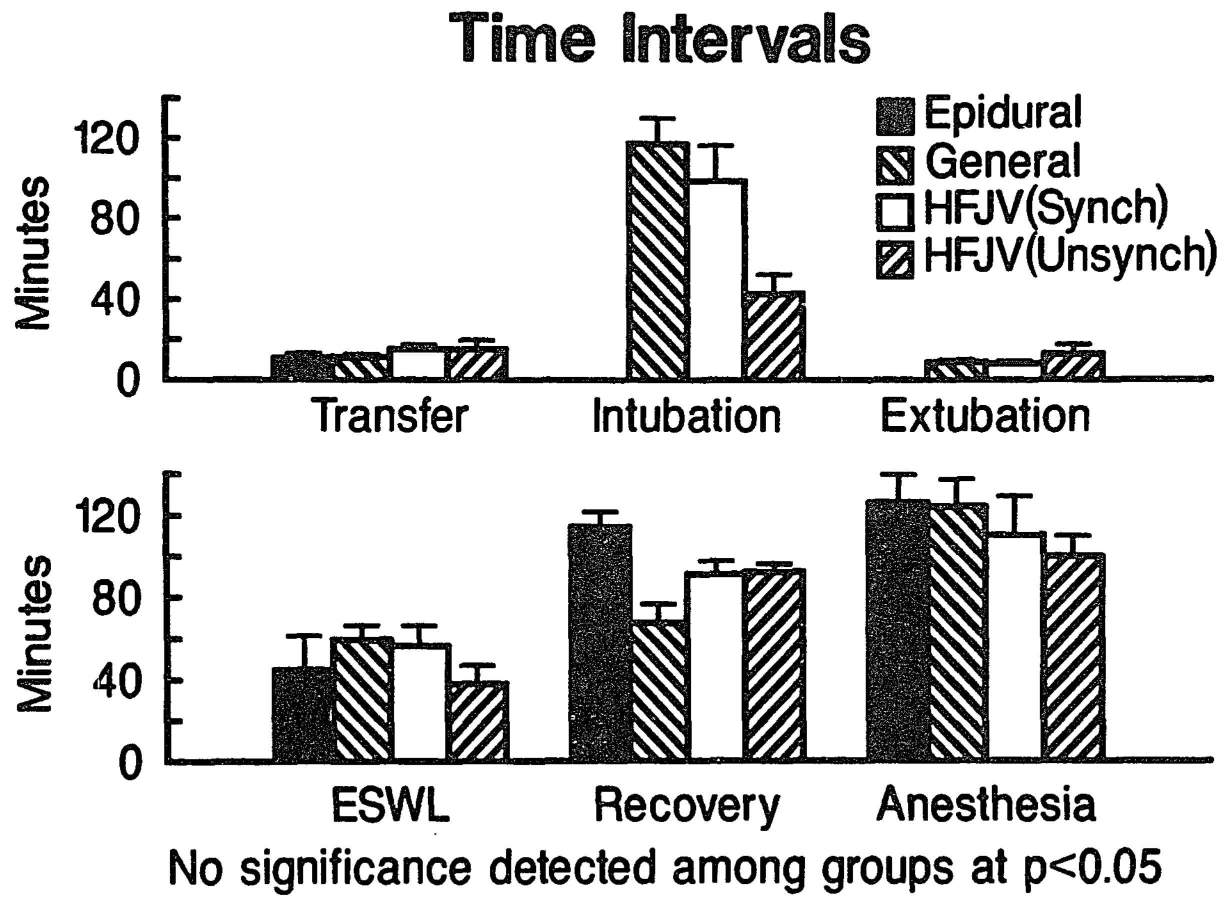
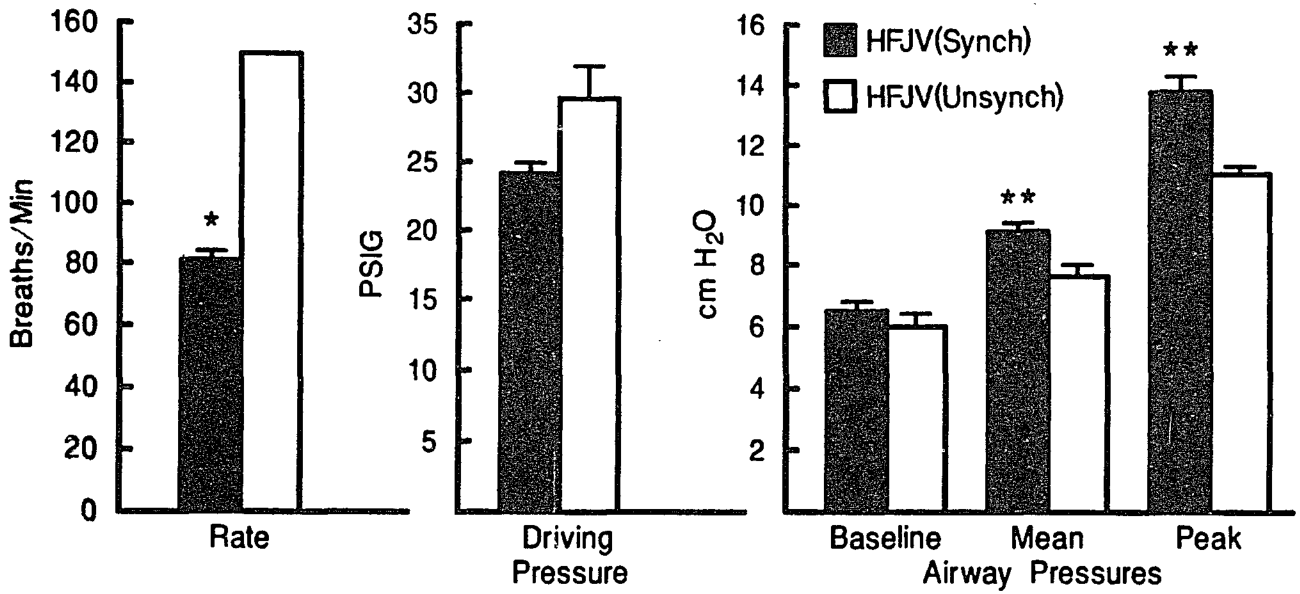


Fig. 8. Time Intervals

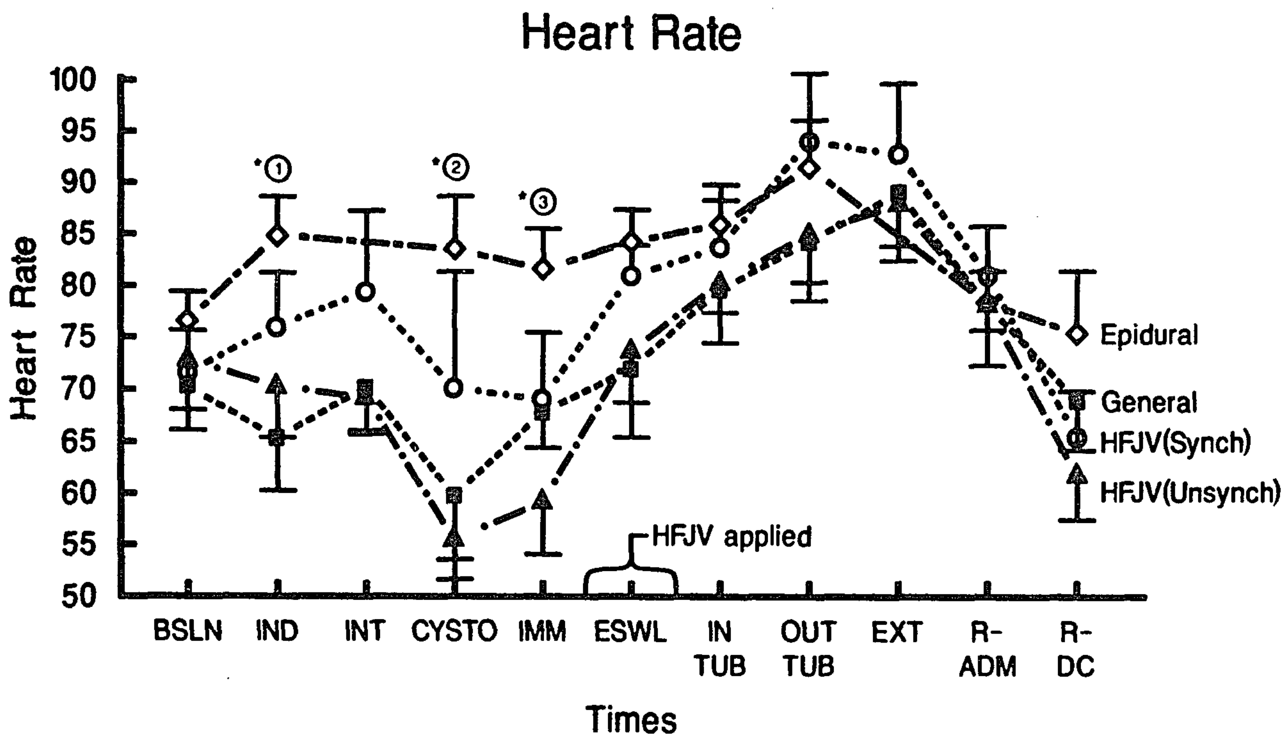


Unless otherwise noted, no significance detected at $p<0.05$

** HFJV(SYNCH) significantly different from HFJV(UNSYNCH) at $p<0.05$

* Significance at $p<0.05$ due to standard rate of 150 breaths/min for HFJV(UNSYNCH) group
Rate = HR for HFJV(SYNCH) group

Fig. 9. HFJV Variables.



*① Epidural Group significantly different from General Group and HFJV (Unsynch) Group at $p<0.05$.
*② Epidural Group significantly different from General Group and HFJV (Unsynch) Group at $p<0.05$.
*③ Epidural Group significantly different from HFJV (Unsynch) Group at $p<0.05$.

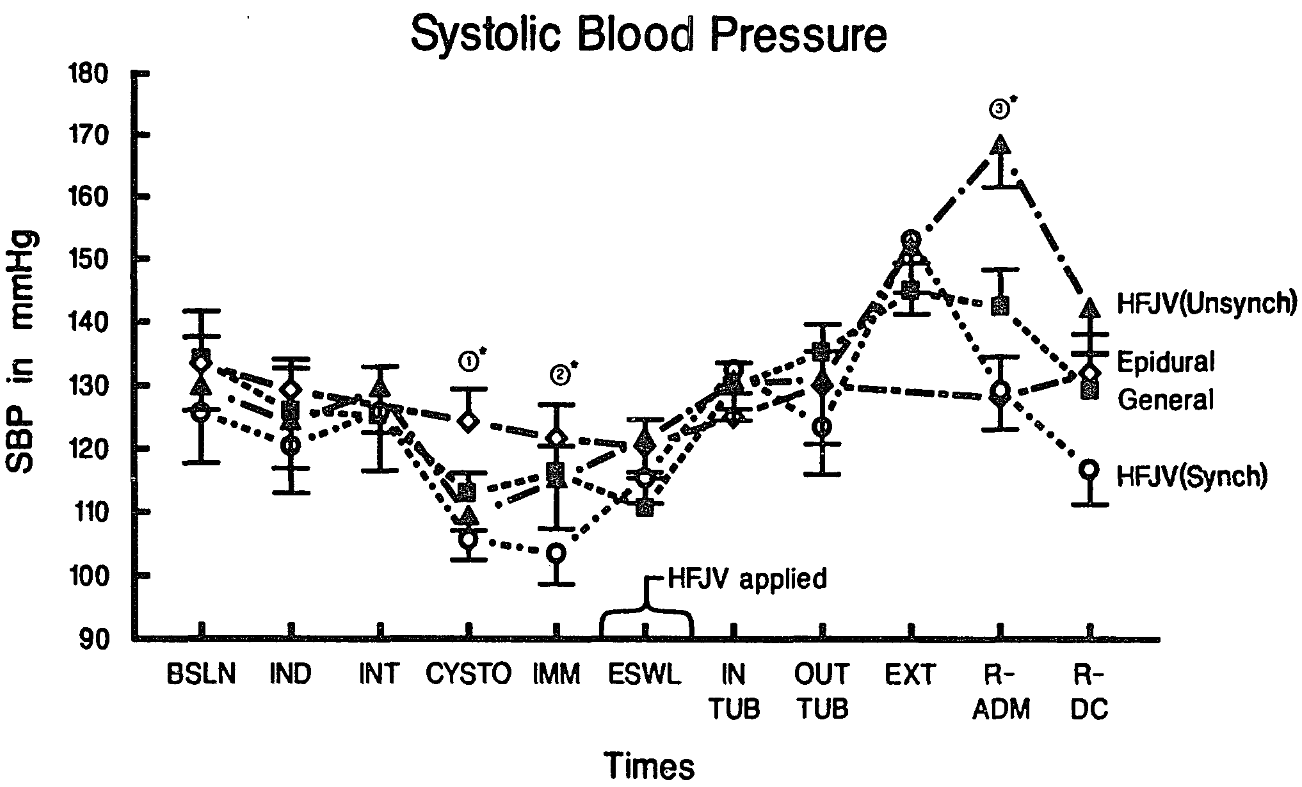
Fig. 10. Heart Rate.

Epidural Group mean heart rate (82 ± 4 b/min) was significantly higher than the HFJV(unsynch) Group (59 ± 5 b/min).

Fig. 11 shows that significant differences in systolic blood pressure values occurred during cystoscopy (CYSTO), at immersion (IMM) and recovery room admission (R-ADM). The Epidural Group mean systolic BP (124 ± 5 mmHg) was significantly higher during cystoscopy than all three other study groups [General (113 ± 3 mmHg), HFJV(synch) (106 ± 3 mmHg), HFJV(unsynch) (109 ± 2 mmHg)]. The Epidural Group mean systolic BP (122 ± 5 mmHg) was significantly higher than the HFJV(synch) Group (104 ± 5 mmHg) at immersion. At recovery room admission (R-ADM), the mean systolic BP value for the HFJV(unsynch) Group (168 ± 6 mmHg) was significantly higher than all three other groups [Epidural (128 ± 6 mmHg), General (143 ± 6 mmHg), HFJV(synch) (129 ± 6 mmHg)].

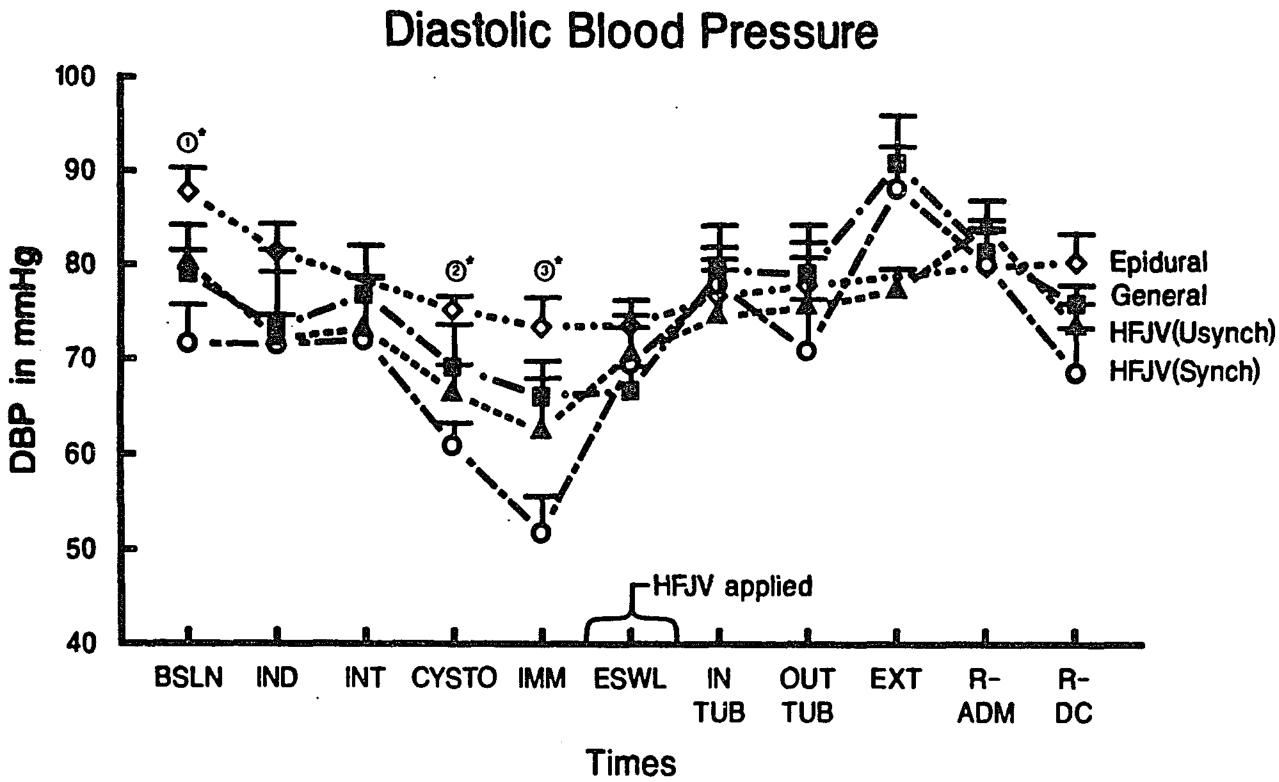
For diastolic BP values (Fig. 12), significant differences among groups occurred at baseline (BSLN), during cystoscopy (CYSTO), and at immersion (IMM). The Epidural Group mean diastolic BP (88 ± 3 mmHg) was significantly higher than the HFJV(synch) Group (72 ± 4 mmHg) at baseline and during cystoscopy [Epidural (75 ± 1 mmHg), HFJV(synch) (61 ± 3 mmHg)]. At immersion, both the Epidural Group mean diastolic BP (73 ± 3 mmHg) and the General Group mean diastolic BP (66 ± 4 mmHg) were higher than the HFJV(synch) Group (52 ± 5 mmHg).

Significant differences occurred for mean blood pressure values (Fig. 13) at only two time periods. At immersion (IMM),



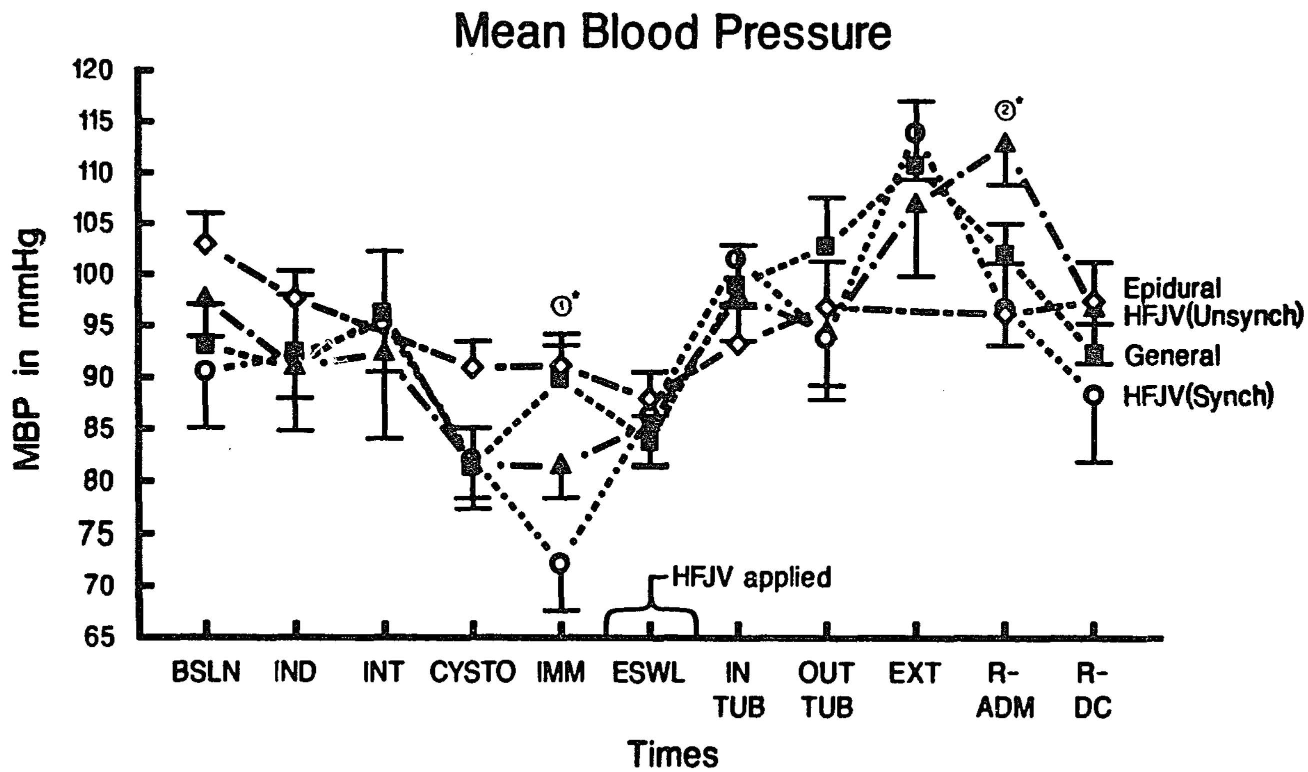
①* Epidural Group significantly different from all 3 other groups at $p<0.05$
②* Epidural Group significantly different from HFJV(Synch) Group at $p<0.05$
③* HFJV(Unsynch) Group significantly different from all 3 other groups at $p<0.05$

Fig. 11. Systolic Blood Pressure.



①* Epidural Group significantly different from HFJV(Synch) Group at $p<0.05$
②* Epidural Group significantly different from HFJV(Synch) Group at $p<0.05$
③* HFJV(Synch) Group significantly different from Epidural and General Group at $p<0.05$

Fig. 12. Diastolic Blood Pressure.



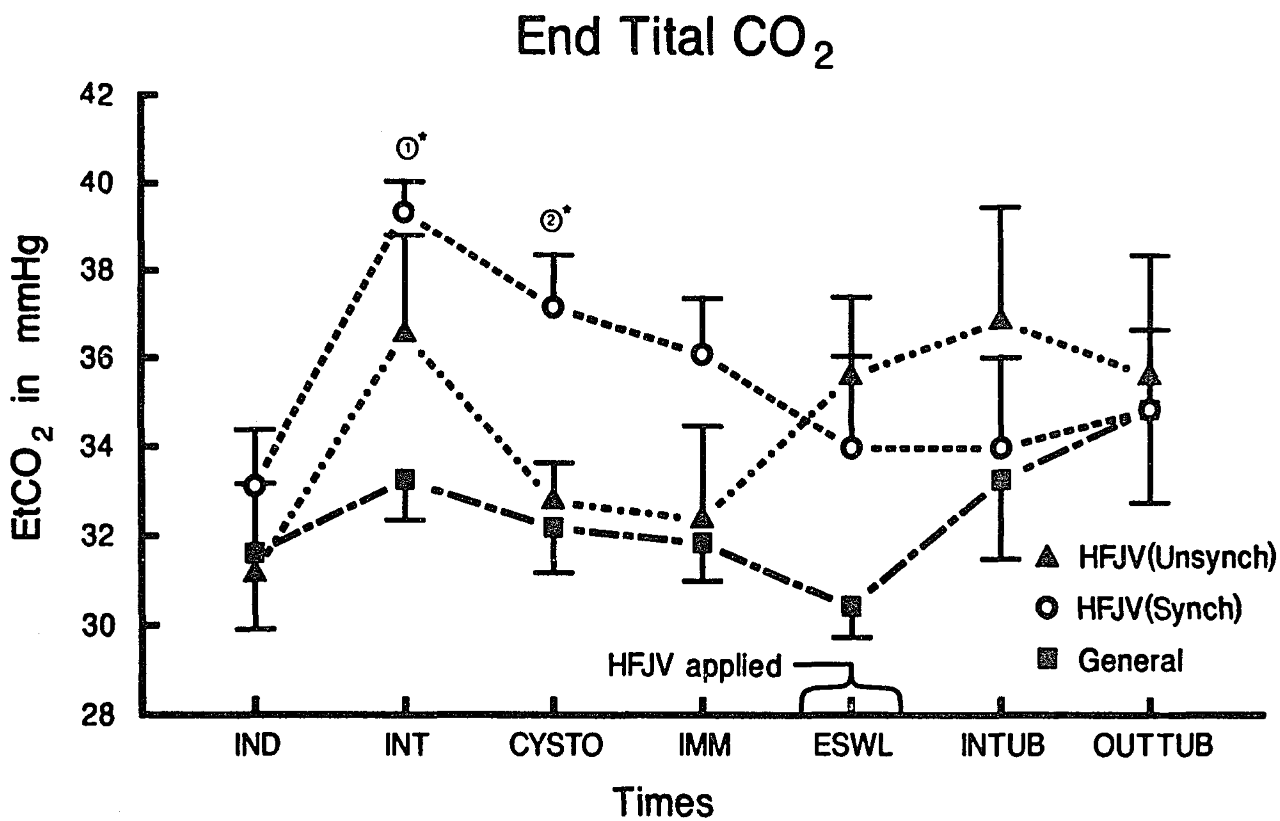
①* HFJV(Synch) Group significantly different from Epidural Group and General Group at $p<0.05$
②* HFJV(Unsynch) Group significantly different from Epidural and HFJV(Synch) Group at $p<0.05$

Fig. 13. Mean Blood Pressure.

both the Epidural Group mean BP (91 ± 3 mmHg) and the General Group mean BP (90 ± 3 mmHg) were significantly higher than the HFJV(synch) Group (72 ± 5 mmHg). At recovery room admission (R-ADM), the HFJV(unsynch) Group mean blood pressure (113 ± 4 mmHg) was significantly higher than both the Epidural Group (96 ± 5 mmHg) and the HFJV(synch) Group (97 ± 4 mmHg).

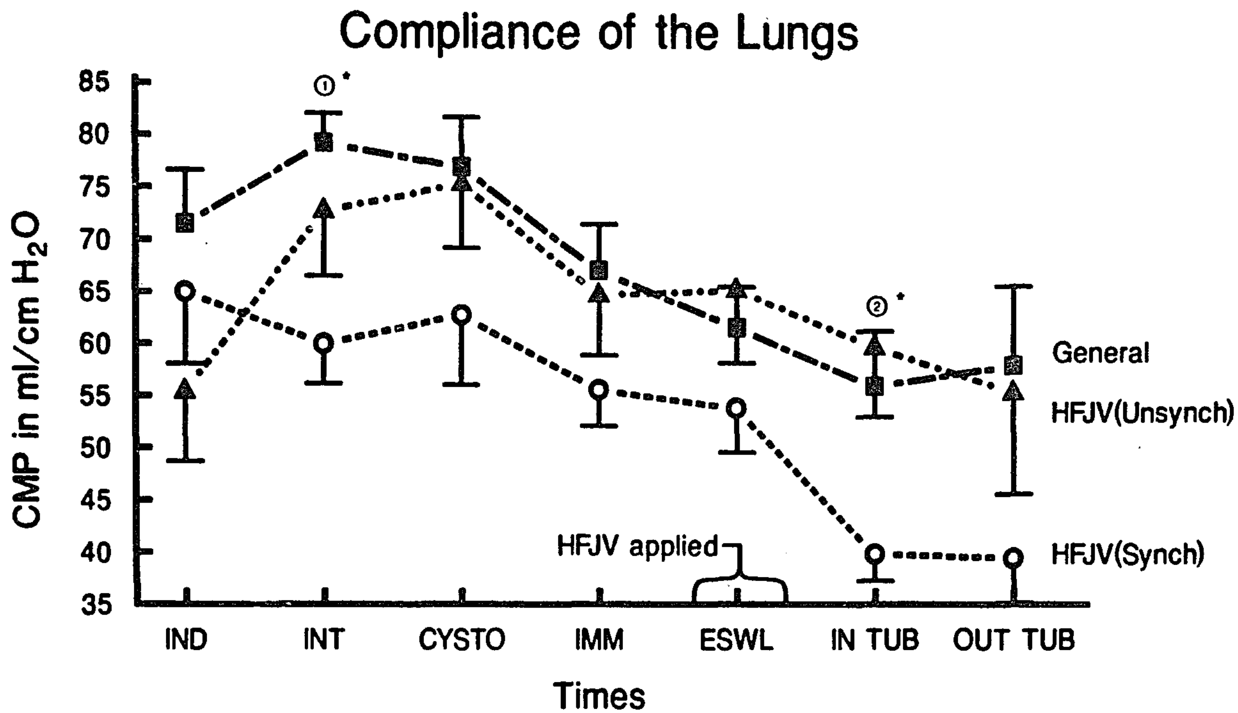
End tital CO_2 (Et CO_2) results for the three study groups is depicted in Fig. 14. Significant differences among the groups occurred at intubation (INT) and during cystoscopy (CYSTO). At intubation, mean Et CO_2 was significantly higher in the HFJV(synch) Group (39 ± 0.7 mmHg) than the General Group (33 ± 0.9 mmHg). During cystoscopy, mean Et CO_2 was significantly higher in the HFJV(synch) Group (37 ± 2 mmHg) than both the General Group (32 ± 1 mmHg) and the HFJV(unsynch) Group (33 ± 0.9 mmHg).

Mean pulmonary compliance results (Fig. 15) show significant differences among groups occurred during cystoscopy (CYSTO) and immediately post-ESWL, but while the subject was still in the tub (IN TUB). Mean compliance was significantly lower in the HFJV(synch) Group (60 ± 4 ml/cm H_2O) than the General Group (79 ± 3 ml/cm H_2O) at intubation. At IN TUB, the HFJV(synch) Group mean compliance (40 ± 2 ml/cm H_2O) was significantly lower than both the General Group (56 ± 5 ml/cm H_2O) and the HFJV(unsynch) Group (60 ± 7 ml/cm H_2O).



①* HFJV(Synch) Group significantly different from General Group at $p<0.05$
②* HFJV(Synch) Group significantly different from General and HFJV(Unsynch) Group at $p<0.05$

Fig. 14. End Tital CO_2.



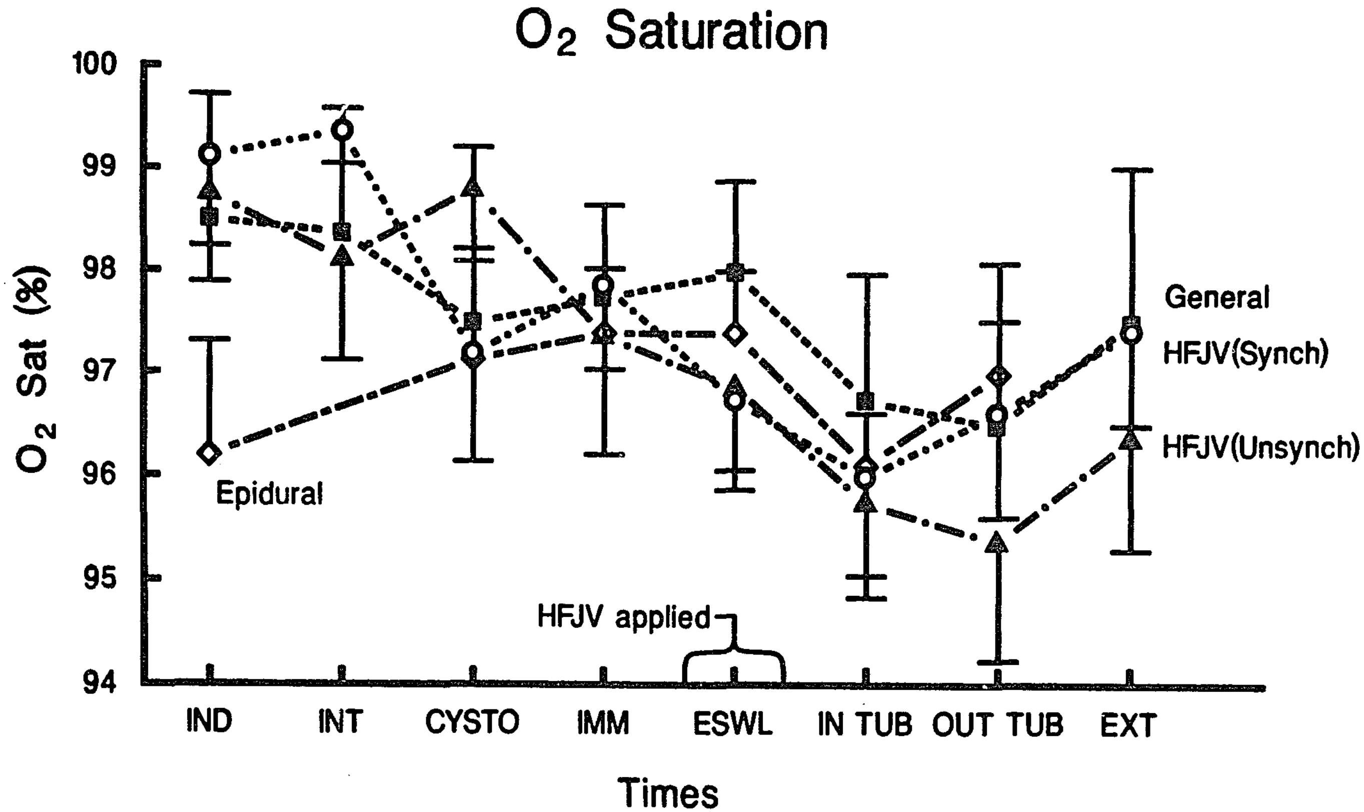
①* HFJV(Synch) Group significantly different from General Group at $p<0.05$

②* HFJV(Synch) Group significantly different from General Group and HFJV(Unsynch) Group at $p<0.05$

Fig. 15. Compliance of the Lungs.

The last three graphs show the results of O_2 saturation (Fig. 16), resistance of the lungs (Fig. 17), and work of inspiration of the lungs (Fig. 18). None of these variables showed significant differences among the study groups. They do, however, show interesting trends that will be discussed in the following section.

In Table 2 are three smaller tables that show the results of follow-up KUB exams among the four groups, complications and follow-up KUB exams between non-HFJV and HFJV groups. The last table divides the original four study groups into a Non-HFJV Group (Epidural Group and General Group) and a HFJV Group (HFJV(synch) Group and HFJV(unsynch) Group). Significant differences occurred only in the last table showing follow-up KUB exams between the non-HFJV Group and the HFJV Group. The reported complications were kidney infections found on the subject's follow-up physical exam after ESWL treatment.



No significant differences detected at $p<0.05$.

Fig. 16. Oxygen Saturation.

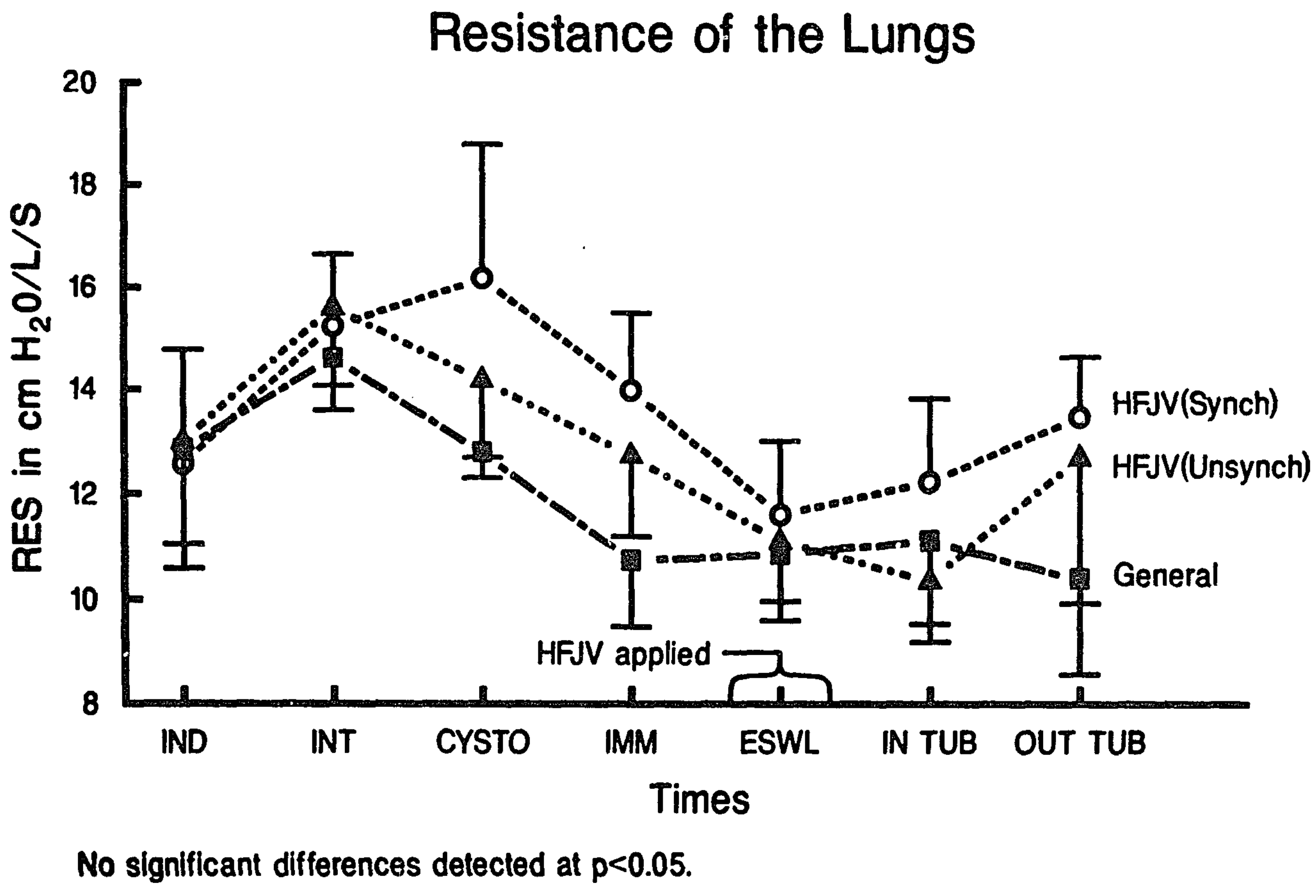


Fig. 17. Resistance of the Lungs.

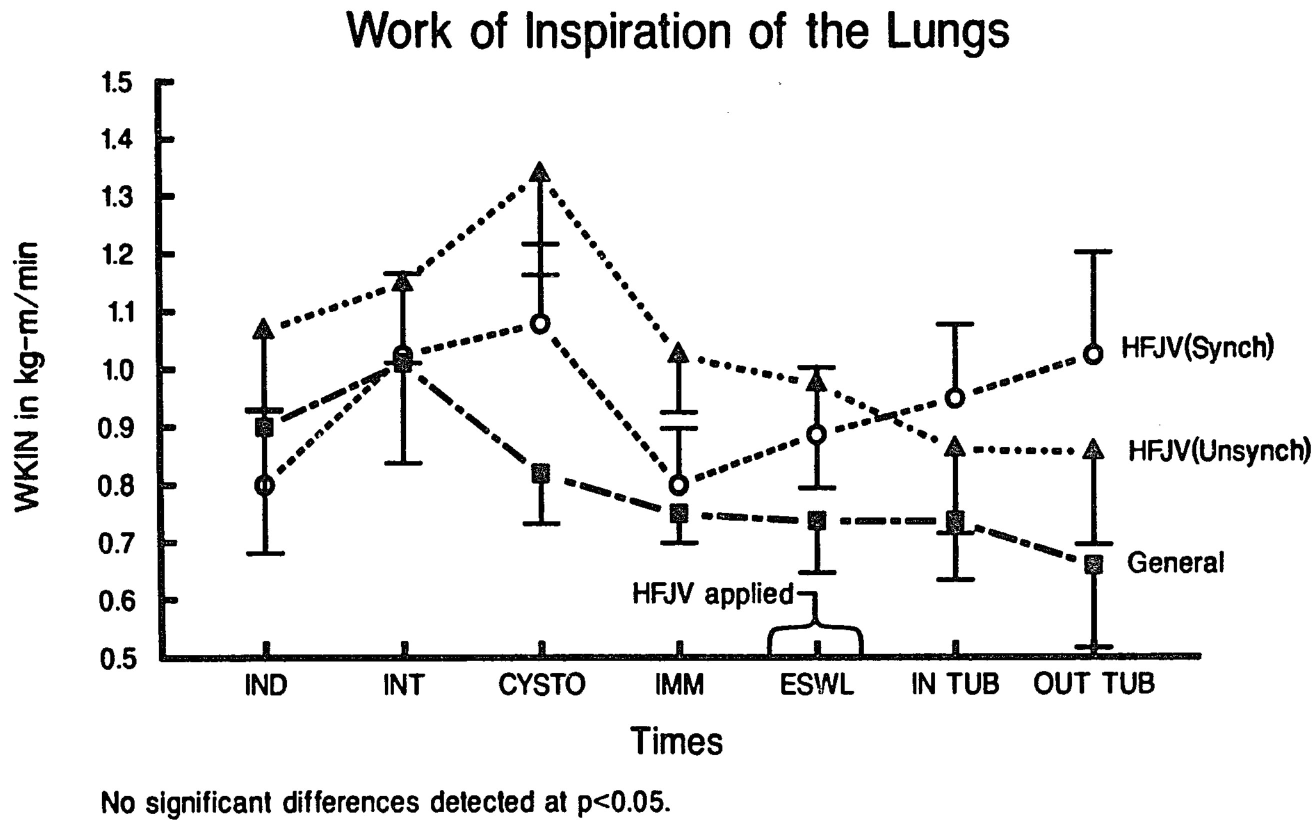


Fig. 18. Work of Inspiration of the Lungs.

Table 2. Follow-up KUB Results Among Groups, Complications and Follow-up KUB Results Between Groups.

Follow-Up KUB Results Among All Groups

KUB Results	EPI # of Subjects	General # of Subjects	HFJV (Syn) # of Subjects	HFJV (Unsyn) # of Subjects
Success	4	5	6	6
Failure	2	2	0	0

Complications Post ESWL

Complications	EPI # of Subjects	General # of Subjects	HFJV (Syn) # of Subjects	HFJV (Unsyn) # of Subjects
Yes	0	2	0	0
No	6	5	6	6

Follow-Up KUB Results Between Groups

	Non-HFJV	HFJV
Success	9	12*
Failure	4	0

*$p<0.05$ between groups

Chapter 4
DISCUSSION

Using high frequency jet ventilation during ESWL does significantly reduce renal stone excursion. However, our results (General Group, HFJV(synch) Group and HFJV(unsynch) Group) show less stone movement than other studies. For example, Carson et al.[13] reported a mean stone movement of 30.6 mm and 2.2 mm during CMV and HFJV respectively. Both values are more than double the renal stone movement found in our study. Perel et al.[9] reported mean stone movements of 17.8 $\pm$ 8.8 mm during CMV and Shulte am Esch et al.[15] reported mean stone movements of 2-3 mm during HFJV. These results also show greater renal stone movement than our results. Zeitlin et al.[14] found mean stone movements of 10.0 $\pm$ 4.2 mm during quiet respiration in 21 patients receiving epidural anesthesia during ESWL. This is similiar to our results for the Epidural Group. The difference in mean stone movement results between other studies and our General Group, is most likely due to the fact that our General Group received LVCMV which uses smaller tidal volumes than CMV. Also, stone movement measurements can only be considered a close approximation since the floroscopy screen itself does not have a measurement grid. Perel et al.[9] noted that the magnification factor of the floroscopy screen (2-2.5-fold) is dependent upon patient size, positioning of the image intensifier, and the electronic magnification factor of the screen itself. Therefore, actual stone excursion can only be considered an estimation in studies of this nature.

The results showing longer ESWL and x-ray times for bilateral stone patients was expected. Bilateral stones require positioning for each kidney which leads to an increase in the amount of fluoroscopy in order to position each stone correctly. Therefore, the results confirm that bilateral stone patients are exposed to higher levels of radiation and are under anesthesia longer than non-bilateral stone patients.

Results found for the HFJV variables can be summarized as follows. In order to maintain O_2 saturation > 95% and Et CO_2 < 40 mmHg, it was necessary to increase the drive pressure as the respiratory frequency increased. This resulted in a decrease of the airway pressures. Our result differs from a study by Rouby et al.[16] that found no significant differences in mean airway pressures until a frequency of 400 pulses/min or higher was obtained and then the mean airway pressure increased significantly. However, both the driving pressure and % inspiratory time were held constant in their study and no attempt was made to maintain either an O_2 saturation or Et CO_2 value. Another study found no significant differences in mean airway pressures when the respiratory frequency was increased from 120 pulses/min to 180 pulses/min.[17] The study involved dogs as subjects and the driving pressure was adjusted to maintain a P_aCO_2 (arterial blood gas) of 40 $\pm$ 5 Torr, but no mention is made of the % inspiratory time. Consequently, no direct correlation can be made between our results and other studies. It appears that adjusting drive pressure, to maintain acceptable levels of O_2 saturation and Et CO_2 results in lower airway pressures at the respiratory frequencies used.

Several interesting results among groups occurred with heart rate and blood pressure. The Epidural Group had significantly higher heart rates from post-induction until ESWL treatment began. This contradicts other studies that found no significant differences in mean heart rates between epidural and CMV-treated groups.[18,19] Two possible reasons are given for the differences between our results and other studies. These are that the epidural may have failed to properly anesthetize the patient and, from the author's observance, several patients in the Epidural Group appeared anxious and apprehensive before the procedure. Unfortunately, there is still no currently acceptable method to statistically analyze either pain or human emotion.

Blood pressure results also reveal contradictions with reported studies. The Epidural Group had significantly higher systolic, diastolic and mean blood pressures from cystoscopy until ESWL and the General Group had significantly higher diastolic and mean blood pressures at immersion. However, the Epidural Group had significantly higher mean diastolic blood pressures preoperatively. Further analysis was done on the diastolic blood pressure results. Percent changes were calculated between cystoscopy and immersion and between immersion and ESWL. These were analyzed among groups with one-way analysis of variance tests. The results confirm that the Epidural Group and General Group had significantly higher mean diastolic blood pressure values ($p < 0.05$) than the HFJV(synch) Group at immersion. Results of other studies contradict this in that they show hypotension during ESWL is more apt to occur in patients receiving regional anesthetics (epidural and spinal anesthesia).[18,19] London et al.[19] reported an 18.7% occurance of decreased mean blood pressure in their Epidural Group. Abbott et al.[18] reported hypotension severe enough to require medication to restore the blood pressure to an acceptable level in 20% of their epidural population. Again, reasons for the differing results are the same as stated earlier when discussing the heart rate results. Carson et al.[20] reported no significant differences in blood pressures between their CMV and HFJV (rate 100: percent inspiratory time 20%: drive pressure varied) groups.

Heart rate trends follow a specific pattern in all groups. All groups show a decrease in heart rate until either cystoscopy (General Group and HFJV(unsynch) Group) or immersion(Epidural Group and HFJV(synch) group). Heart rates then increase until either after the subjects are removed from the tub (Epidural Group and HFJV(synch) Group) or at extubation (General and HFJV(unsynch) Group). At recovery room discharge, all groups appear to have mean heart rates close to baseline values.

Trends for blood pressures are similiar in that mean blood pressure values decrease until immersion, except the General Group which showed mean blood pressures increasing. Mean blood pressures then increase until extubation, except for the HFJV(synch) Group which showed mean blood pressures increasing further to recovery room admission and the General Group which remains stable. Mean blood pressures for all groups appear to return close to baseline values at recovery room discharge. Our results that showed mean blood pressures decreased at immersion correlate well with previous studies that explored cardiovascular effects on ESWL patients under general and regional anesthesia.[21]

The respiratory parameters revealed few significant results among the general anesthesia groups (General Group, HFJV(synch) Group and HFJV(unsynch) Group). The significantly higher Et CO_2 readings obtained for the HFJV(synch) Group occurred before HFJV was applied. The only difference in anesthetic technique during intubation and cystoscopy was that higher tidal volumes were used in the HFJV groups. Therefore, significant differences should not have occurred among the groups before ESWL. The non-significant Et CO_2 results obtained after HFJV was applied are justifiable in that the HFJV settings were constantly adjusted in order that Et CO_2 remained below 40 mmHg for all groups.

Results for pulmonary compliance merited further statistical analysis due to the HFJV(synch) Group having significant differences from the General Group before HFJV was applied. The percent change in compliance from ESWL to IN TUB was calculated and analyzed by one-way analysis of variance among groups. The results proved insignificant at $p < 0.05$. The lower mean compliance for the HFJV(synch) Group at intubation does correlate with the lower Et CO_2 results obtained for the group at the same time since less compliant lungs can result in higher Et CO_2 values.

The trends for compliance and resistance of the lungs follow patterns that are similar for all groups over time. It must be clarified that the airway resistance measured by the Critikon Anesthesia Respiratory Monitor (Model 8510) represents non-elastic resistances. Compliance represents the reciprocal of elastic resistance. Arborelius[22] reported that functional residual capacity (FRC) decreased when the body was immersed into water due to the effect of hydrostatic water pressure. Since compliance is inversely porportional to changes in pressure, it would be probable this value would decrease with immersion which does correlate with our results.

Although no significant differences occurred among groups at $p < 0.05$ for calculated power and length of ESWL treatment, these results may not be meaningful. Because of the difficulty in determining actual stone disintegration during ESWL, it is the author's observation that physicians would continue to treat urinary stones, for fear of re-treatment, even though the stone appeared disintegrated on x-ray. This would result in longer treatment times and greater power values. This may be the reason no significant differences occurred among groups for these categories.

There were no significant differences when follow-up KUB results were analyzed among the four groups. However, when the four groups were split into a Non-HFJV Group and a HFJV Group, significant differences were found. A correlation between significantly less renal stone excursion and significantly less occurances of treatment "failures" can be drawn for the HFJV treated groups. Therefore, it appears that minimizing renal stone movement during ESWL is important and can be accomplished by using HFJV.

In conclusion, synchronizing HFJV to the human cardiac cycle does not appear to have any more beneficial effects than unsynchronized HFJV during ESWL in terms of the results presented here. However, the use of HFJV during ESWL does improve the procedure by decreasing the amount of patients who would require re-treatment. Further, if a definite endpoint in stone disintegration can be found during ESWL, perhaps results will show that using HFJV also significantly reduces the power used and the length of treatment. Lastly, even though the epidural group did have higher mean heart rates and mean blood pressures, no results indicate that the use of general anesthesia is a better method than epidurals.

List of References

1) Drach GW, Dretler S, Fair W, et al: Report on the United States cooperative study of extracorporeal shock wave lithotripsy. Journal of Urology 135:1127-1133, 1986

2) Cavanaugh M: Lithotripsy makes an Impact. Biomedical Technology Today 2(6):178-182, 1987

3) Office of Technology Assesment. 1986. Effects of Federal Policies on Extracorporeal Shock Wave Lithotripsy. Case Study 36. Washington, D.C.: Congress of the United States

4) Mulley AG Jr.: Shock wave lithotripsy: Asessing a slambang technology. New England Journal of Medicine 314:845-847, 1986

5) Crockett AT: Extracorporeal shock wave lithotripsy training in the United States (editorial). Journal of Urology 135:1229, 1986

6) Hamilton LH: Historical Development of High Frequency Ventilation. In High Frequency Ventilation. CRC Press, Inc.,1986

7) Kirby RR, Carlon GC: Practical and Ethical Considerations. In High Frequency Ventilation in Intensive and During Surgery. Marcel Dekker, Inc., 1985

8) Schulte am Esch J, Kochs E, Meyer WH: High frequency jet ventilation diuring extracorporeal shock wave lithotripsy. Anaesthesist 34(6):294-298, 1985

9) Perel A, Davidson JT, et al: High frequency positive pressure ventilation during general anesthesia for extracorporeal shock wave lithotripsy. Anesthesia and Analgesia 65(11):1231-1234, 1986

10) Meyer WH, Becker H: Higher efficiency of extracorporeal shock wave lithotripsy by the use of high frequency jet ventilation (abstract). Journal of Urology 135(4):A150, 1986

11) Berger JJ, Boyson PG et al: Failure of high frequency jet ventilation to ventilate patients during extracorporeal shock wave lithotripsy. Anesthesia and Analgesia 66:262-263, 1987

12) Griffith DP, Valiquette L: PICA/Burden: A staging system for upper tract urinary stones. Journal of Urology 138:253-257, 1987

13) Carson CA, Boysen PG, et al: Conventional vs. high frequency jet ventilation for extracorporeal shock wave lithotripsy (abstract). Anesthesiology 63(Suppl 3A):A530, 1988

14) Zeitlin GL, Roth RA: Effect of three anesthetic techniques on the success of extracorporeal shock wave in nephrolithiasis. Anesthesiology 68:272-276, 1988

15) Schulte am Esch J, Kochs E, et al: Improved efficiency of extracorporeal shock wave lithotripsy during high frequency jet ventilation (abstract). Anesthesiology 63(Suppl 3A):A177, 1985

16) Rouby JJ, Simoneau G, et al: Factors influencing pulmonary volumes and CO_2 elimination during high frequency jet ventilation. Anesthesiology 63:473-482, 1985

17) Otto CW, Quan SF et al: Hemodynamic effects of high frequency jet ventilation. Anesthesia and Analgesia 62:298-304, 1983

18) Abbott MA, Samuel JR, et al: Anaesthesia for extracorporeal shock wave lithotripsy. Anaesthesia 40:1065-1072, 1985

19) London RA, Kudeak T, et al: Immersion anesthesia for extracorporeal shock wave lithotripsy. Urology 28(2):86-94, 1986

20) Carlson CA, Gravenstein JS: Monitoring techniques during anesthesia and HFJV for extracorporeal shock-wave lithotripsy (abstract). Anesthesiology 63(Suppl 3A):A178, 1985

21) Weber W, et al: Cardiopulmonary changes during anesthesia for extracorporeal shock wave lithotripsy (ESWL). Journal of Urology 131:246A, 1984

22) Arborelius M: Hemodynamic changes in man during immersiom with head above water. Avait Space Environ Med 43:592, 1972