

## Electrostimulation of erection and ejaculation and collection of semen in spinal cord injured humans

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**Abstract**—An electrostimulation system developed for early research with humans and the great apes, and a new constant-current stimulator specifically developed for human use, have been employed in studies with paraplegic men to produce erection and semen release by rectal probe electrostimulation (RPE). Catheter techniques for antegrade collection of the semen, uncontaminated by urine, have also been applied with moderate success. Details of the electronic instrumentation and catheter techniques are given. The procedure used with the patients and electrostimulation and semen collection results are presented.

### INTRODUCTION

After our success with rectal probe electrostimulation (RPE) of the great apes (16) and many smaller primates (9), it occurred to us that perhaps the technique could be applied to paraplegic men for partial sexual rehabilitation. Since the great apes are under ketamine anesthesia (administered for animal control) during the procedure, it appeared that RPE was causing erection and semen release via the reflex arcs with little, if any, brain mediation. We hoped the same would be true in paraplegic men since a complete or nearly complete transection injury to the spinal cord should essentially prevent brain mediation.

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Published reports of the application of electrostimulation to the human male for purposes of erection and/or semen release are scarce; they generally have not described the instrumentation necessary for adequate monitoring of the critical electrical parameters involved nor for protection of the subjects against electrical shock and tissue damage. In general, comparison of the methodology and thus the results is difficult due to the various probe techniques employed. These have included urethral sounds (10), diathermy probes (1), monopolar electrodes (14), finger-cot mounted electrodes (2, 3), and bipolar rectangular metal electrodes mounted on cylindrical plastic material (4, 6, 7, 8). Stimulating current value and electrode dimensions which will allow ejaculation of current density in milliamperes per square millimeter were provided by only one of these groups of workers (3); Brindley's reported peak current and electrode area were 315 mA and 50 mm<sup>2</sup>, respectively. This calculates to a current density of 6.3 mA/mm<sup>2</sup> more than 16 times the value (0.37 mA/mm) which is our limit for safe electrical stimulation of tissue. Although his pulse-train duty cycle of 0.003 allows an average power of 0.0017 W to be dissipated per square millimeter of tissue (our sine-wave average power is 0.004 W), a peak power of 0.56 W is dissipated in each square millimeter of tissue during the 100  $\mu$ s pulse (our peak power is 0.0056 W). This 0.56 W appears to us, even with DC decoupling, to be much too high. The electrical parameter, milliamperes per square millimeter is important for assuring tissue safety (5). Some reports omitted electrical parameters and the electrode dimensions entirely (12, 15).

Objectives of this paper describing our studies involve

1) generation, amplification, control, and monitoring of the important electrical parameters involved in the stimulation technique; 2) safeguards against electrical shock and electrical tissue damage to the human subjects; 3) delivery of the stimulating current; 4) techniques for antegrade collection of semen released by electrostimulation; and 5) patient procedure and results from the electrostimulation of, and semen collection from, our patient population.

## MATERIALS AND METHODS

### Electronic Instrumentation

The electronic instrumentation system which was employed for stimulation during our earlier human work (11) and some of our later animal studies (9) is shown in **Figures 1A** and **1B**. Briefly, a single-channel 60 W amplifier was powered through an isolation transformer from the building electrical mains. It was excited by a sine-wave generator via an intensity control. Its output was applied to the rectal probe through a junction box which permitted proper connection of a voltmeter and milliammeter for monitoring of the electrical parameters. A reed relay, variable current limit switch was connected between the output of the power amplifier and the rectal probe and measurement circuits. It was set to trip when for any reason a total current flowed in excess of that allowable for tissue safety. The stimulating waveform applied was sinusoidal and frequencies between 0.25 Hz and 100 Hz were studied for stimulation efficiency. Early work with the great apes (16) revealed that with RPE it was necessary to use a sine wave electrical stimulation waveform exclusively. Inclusion of any high-frequency components, such as are inherent in the rise and fall times of pulses, inhibited penile erection and semen release. This was probably the reason for the unsuccessful earlier attempts to stimulate erection and ejaculation with the use of a pulse waveform with rectal probe stimulation. In fact, if even moderate clipping of the sine wave occurred, immediate inhibition was noted. Frequencies between 20 Hz and 25 Hz proved to be most efficient in both the animal and human studies relative to the lowest current density required at the electrode/tissue interface to produce erection and semen emission.

Two important reasons convinced us to integrate most of the major functions in the stimulation system described previously into a single new instrument. One was our desire to employ constant-current stimulation, even in our low impedance range (50 to 100  $\Omega$ ) application, since

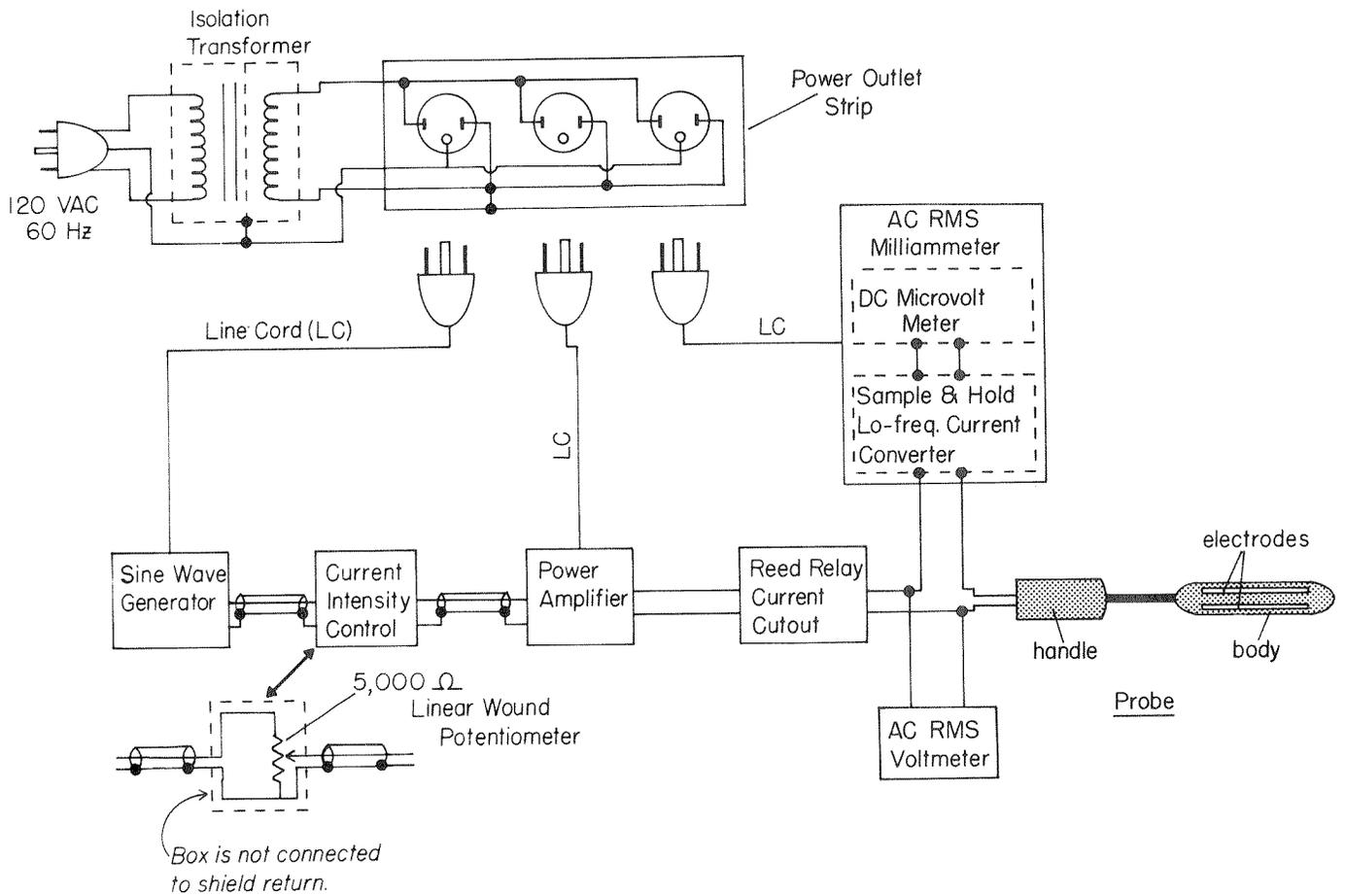
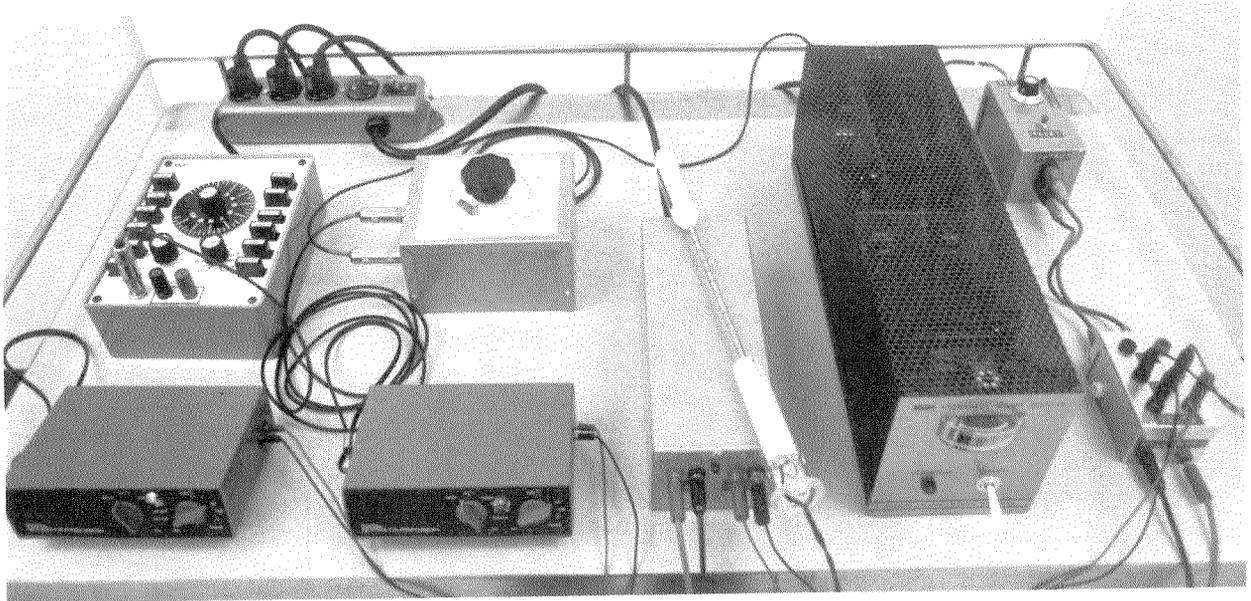
it is electric current which stimulates neuromuscular tissue, and the present solid-state technology could now maintain a constant-current of up to 400 mA RMS through an impedance of up to 58  $\Omega$ , with an output buffer-amplifier direct current source of  $\pm 41$  volts. The second reason was to create an instrumentation which was considerably simpler to operate in general and which could be operated without reluctance by project personnel when it was necessary to stimulate selected patients in the absence of the biomedical engineer.

The new stimulation instrument, two views of which are shown in **Figure 2**, and which we call our "Biomedical Stimulator Model 3," was developed in the biomedical engineering laboratories of the Yerkes Regional Primate Research Center. It accepts power through an isolation transformer from either 110 or 220 volts RMS at 50 or 60 Hz, selected by a switch inside the cabinet. The building safety ground is carried by the line cord only to the instrument metal housing. None of the stimulation circuits returns to this housing. Its sine wave electrical stimulation output is a constant-current of 0 to 400 mA and is capable of driving up to 58  $\Omega$  at 400 mA, undistorted. For loads above 58  $\Omega$  the maximum constant-current in milliamperes is given by:

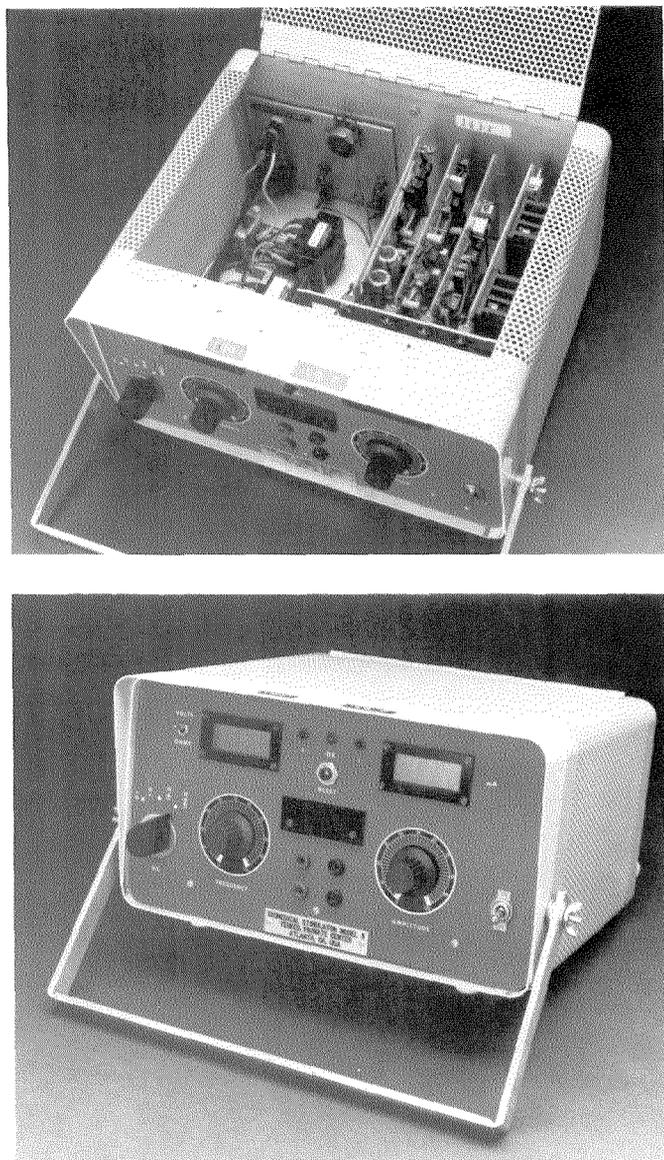
$$I = \frac{23.2}{|Z|_L}$$

where  $I$  is the current in milliamperes and  $|Z|_L$  is the magnitude of the load impedance in ohms. The frequency of the sine-wave output of this instrument may be varied from 10 to 100 Hz.

On the back panel of the stimulator is a control which sets the maximum safe value of the output current. When the output current passes that value, a semiconductor switch interrupts the current flow by turning off the power supply rails and, as an added safety feature, opens the reed relays and turns on a red light-emitting diode on the front panel. To reset the instrument, the current amplitude control on the front panel first must be lowered; then the reset switch, also located on the front panel, may be operated. The value of the constant-current output can be read out at all times from a digital meter on the right end of the front panel. Another front-panel-mounted digital meter on the left indicates either the voltage across the probe output or the magnitude in ohms of the electrode/tissue interface impedance (voltage divided by the current) as selected by a switch near the meter face. With the frequencies used for stimulation, this impedance is largely resistive, although there is a small capacitive reactive component. Accordingly, it is the absolute value



**Figure 1** Early stimulation system consisting of separate, interconnected components. **A:** Photograph of system. **B.** Block diagram of system.



**Figure 2**

Two views of the new, integrated, stimulation instrument showing the front panel, and the modular plug-in boards inside the unit.

or magnitude of the impedance that is displayed on the meter. A combination block/schematic diagram of the instrument is shown in **Figure 3**.

### Signal-Flow and Circuit Operation

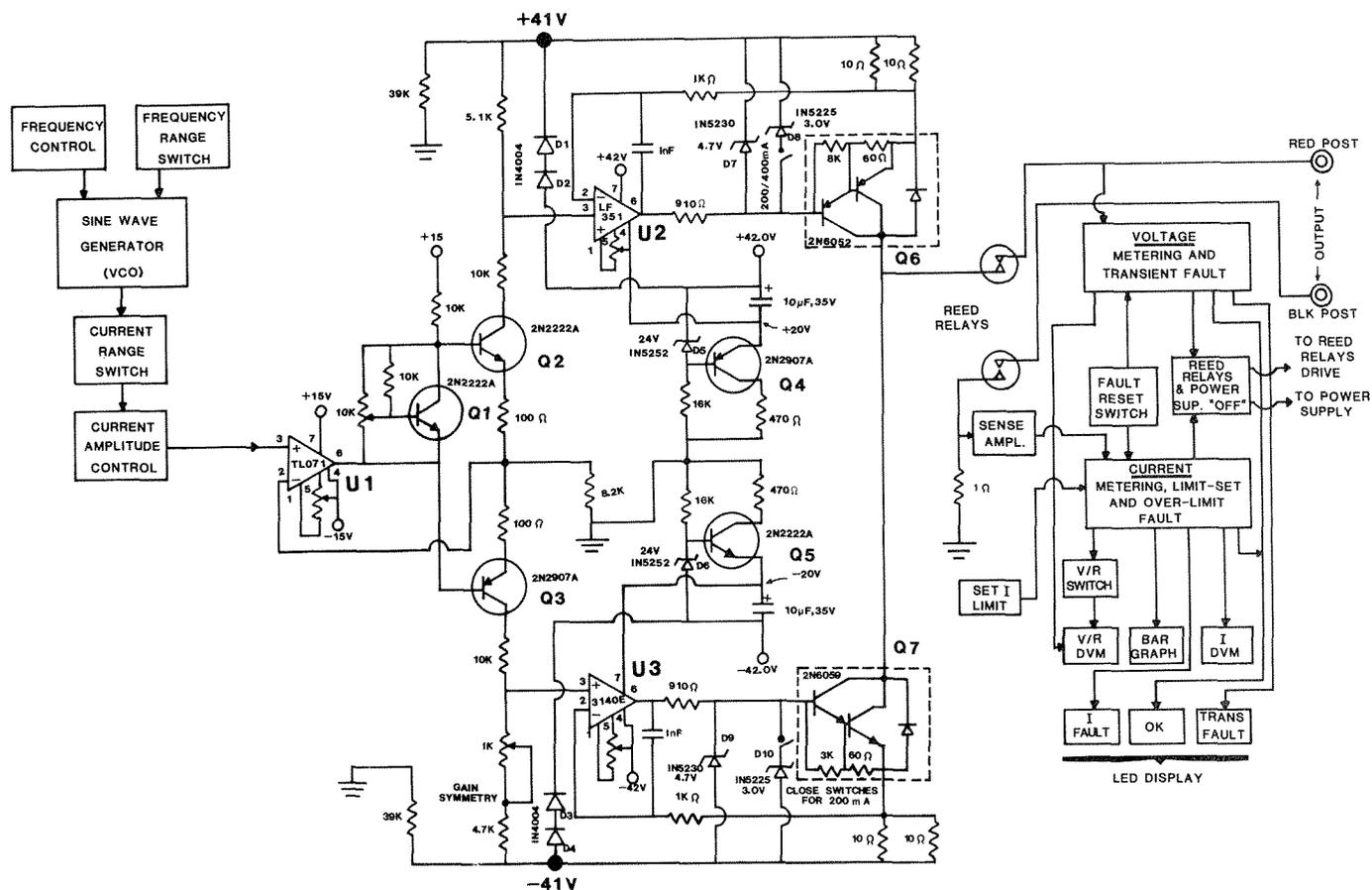
The block diagram portions of **Figure 3** are general state-of-the-art circuitry and thus a schematic representation of these is considered unnecessary here. However,

the schematic portion of **Figure 3**, the constant-current high-power feedback amplifier, is shown in schematic form since we believe this is in advance of the state of the art.

A voltage-controlled oscillator sine wave generator with variable and multiple range frequency control, drives the current-amplitude control on the front panel of the instrument through a 2-level current range switch which permits either a 200 mA or 400 mA maximum current range to be selected. Voltage output from this amplitude control is impressed on pin 3 of operational amplifier U1 in the schematic portion of this combination figure (**Figure 3**). U1 along with transistors Q1, Q2 and Q3 split the positive and negative portions of the input voltage sine wave between the positive (+41.0 volts) and the negative (-41.0 volts) DC supply rails, and the circuit return. Controls are supplied for adjusting gain symmetry and balance.

Operational amplifier U2 and power transistor Q6 form the feedback current amplifier for the positive half of the stimulation constant-current output. Drive for the circuit is impressed on pin three of U2, and feedback in the circuit is developed across the parallel 10-ohm resistors and fed back into pin 2 of U2. Operational amplifier U3 and power transistor Q7 form the feedback, current amplifier for the negative half of the stimulating constant-current output in the same manner as the foregoing. The two circuits, one consisting of transistor Q4 and Zener diode D5 and the other consisting of transistor Q5 and Zener Diode D6, are voltage regulators for developing plus and minus 20 volts required by the operational amplifiers in both the positive and negative current feedback loops. The Zener diodes D8 and D10 and the series switches in the bases of the two power transistors form an additional safety circuit to minimize the possibility of overcurrent to the subject. These serve to automatically cut off the power amplifiers at either 200 or 400 mA, as selected by these series switches. Output from the amplifier is through a pair of reed relays to the red and black posts. Note that the constant-current amplifier uses only local feedback; this minimizes the possibility of instability when driving highly reactive loads.

The final block diagram portion of **Figure 3** contains the metering, current limit control, overcurrent and transient faults circuits, fault reset, and fault LED display. Transient faults consist of high-frequency components such as large transients in the power rails, or high-frequency oscillation. These high-frequency components are picked up from the above-ground output of the power amplifier and, if a safe value is exceeded, the reed relays



**Figure 3**  
Combination block/schematic diagram of the new, stimulation instrument.

will open and the power supply rails will turn off. At the same instant the transient-fault red LED will glow and the OK green LED will extinguish. Values of current up to and exceeding that set by the set-current-limit control, or automatically set by the over-bias circuits of the positive and negative power transistors, are sensed by the amplifier across the 1 ohm resistor, amplified, and applied to the current metering, limit-set, and over-limit fault processing circuits. Any current over the limit will open the reed relays, turn off the power supply rails and, at the same instant, turn on the current-fault red LED and turn off the OK green LED. The fault reset switch can be used to clear all fault circuits provided the fault is no longer present.

The actual value of the constant-current set by the current amplitude control is displayed continuously on the digital voltmeter, labeled "I". Another digital voltmeter, labeled "V/R", is employed to display the actual voltage output across the power amplifier, and this meter can be set by the switch, labelled "V/R," to read the

magnitude (in ohms) of the electrode/tissue interface impedance. A bar graph display consisting of a string of LED's serves as an analogue of the current amplitude during stimulation cycling.

### Electrical Shock Safety

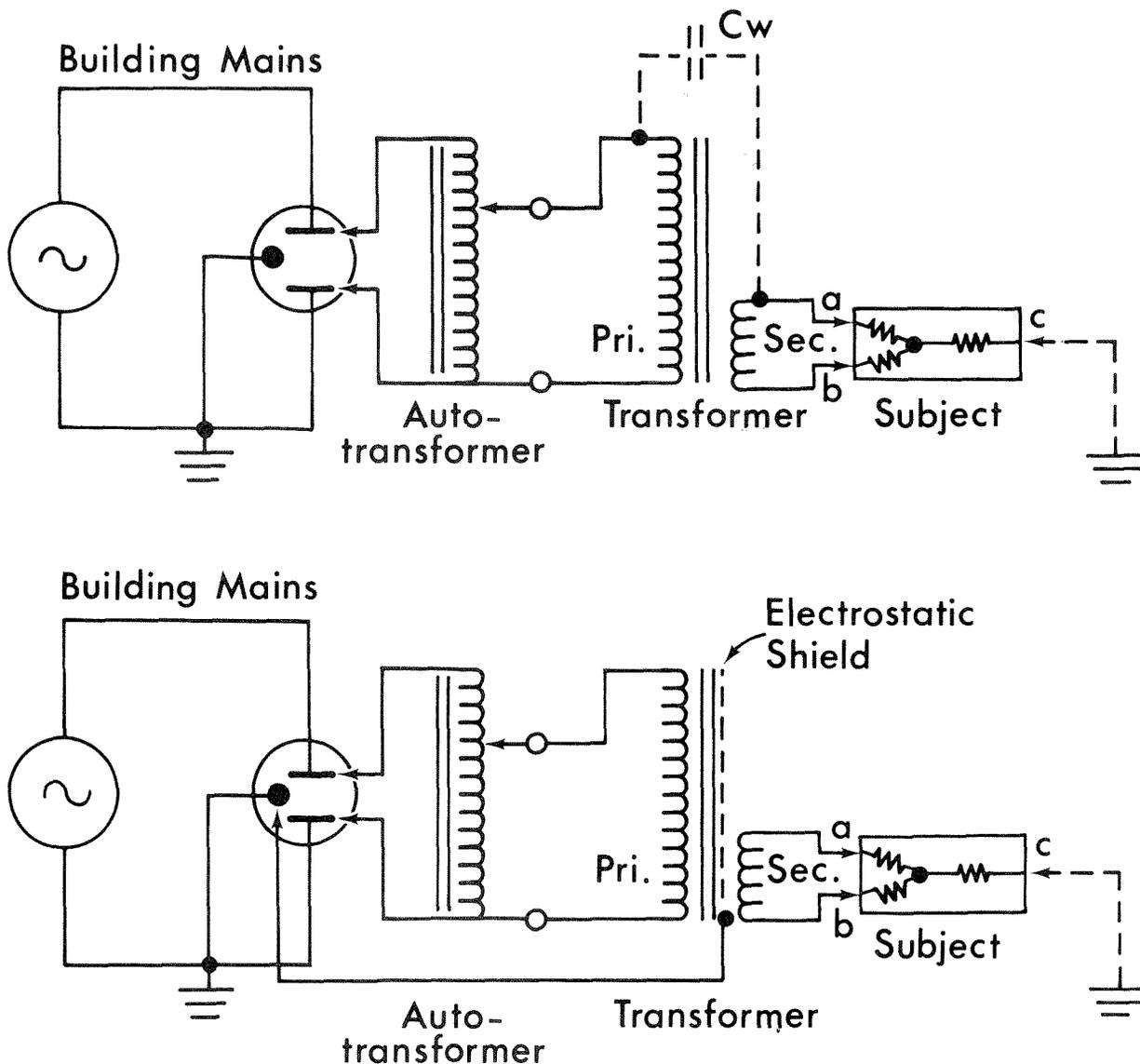
In the design of stimulation instrumentation systems for use with humans, as well as for continuing experiments with animals, we decided to minimize (even further than we had done in our previous work) the shock hazard due to inadvertent grounding of the subject at or above the cardiac level. Previous systems for animal stimulation from the building mains used a simple isolation transformer (Figure 4A) whose output or secondary winding, which supplied the electric current to the stimulation instrumentation, and thus, to the rectal probe electrodes, was conductively isolated from the primary winding and building ground. No attempt was made to minimize the

capacitive reactance pathway back to building power.

This pathway is caused by distributed capacitance (*shown in dotted lines*) between the primary and secondary windings and can reach levels of 500 picofarads and above. Reactive current can then flow from the primary winding through the interwinding capacitance to the subject via the secondary winding and the electrodes, through the subject's upper torso by volume conduction in the tissues, and back to building ground by way of the aforementioned inadvertent ground. With this pathway intact, volume electric currents approaching 50 to 100  $\mu\text{A}$  through the thorax are possible, and thus the danger of ventricular

fibrillation becomes a possibility.

Accordingly, an isolation transformer which includes an electrostatic shield between the primary and secondary windings (**Figure 4B**) was employed to power all of our later instrumentation circuitry. This shield when connected to building ground acts to divide the interwinding capacitance into two portions and to simultaneously ground each portion, thus sharply minimizing the capacitance. By actual "worst-case" measurement the total ground current was reduced to between 1 and 2  $\mu\text{A}$ , which is an extremely safe value.



**Figure 4**  
 Circuits for isolating subjects from the electrical power mains to minimize electric shock hazard. **A.** Transformer for conductive isolation. **B.** Transformer with an electrostatic shield for both conductive and reactive isolation.

## Rectal Stimulating Probes

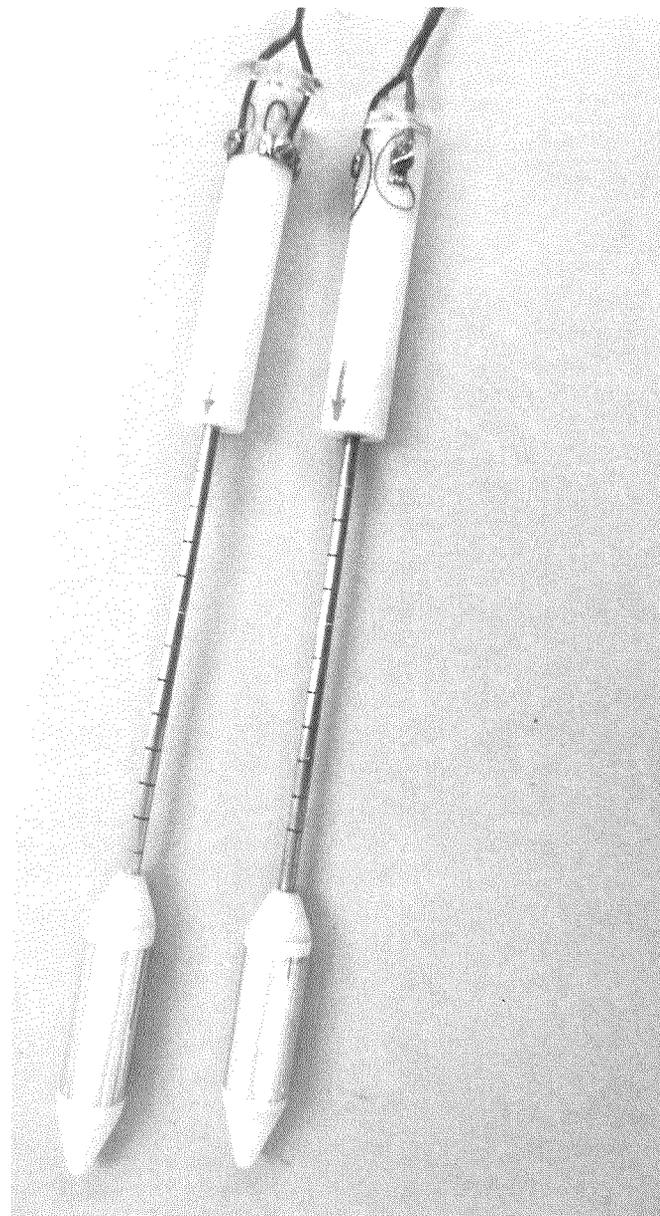
Four plastic rectal probes, two of which are illustrated in **Figure 5**, were designed and fabricated in our laboratories and employed in this study. Each was constructed of Delrin plastic 19 mm in diameter, tapered at the insertion end, and between 65 and 70 mm in length. A narrow stem of tubular stainless steel (4.8 mm in diameter) just behind the probe body was marked in color-coded bands as a guide for insertion depth. Preliminary work has found such a "narrowing" crucial for alleviation of uncomfortable anal sphincter spasm even during very low current flow in the neurologically intact subjects (11). This sphincter region is well-endowed with pressure receptors. A Delrin plastic handle just behind the stem also serves to make connections from the electrodes to the stimulating cable.

Bipolar platinum electrodes of four sizes ( $8 \times 44$  mm = 352 mm<sup>2</sup>;  $10 \times 40$  mm = 400 mm<sup>2</sup>;  $12 \times 42$  mm = 504 mm<sup>2</sup>;  $12 \times 46$  mm = 552 mm<sup>2</sup>) were bonded with adhesive lengthwise to the probe bodies, on centers 120 degrees with respect to each other. This gave each probe directional characteristics to improve resolution in the tissue pattern of current delivery. An arrow painted on the handle indicated the center of symmetry of the electrode pair for proper positioning with respect to the individual's dorsal or ventral midline.

## Antegrade Semen Collection

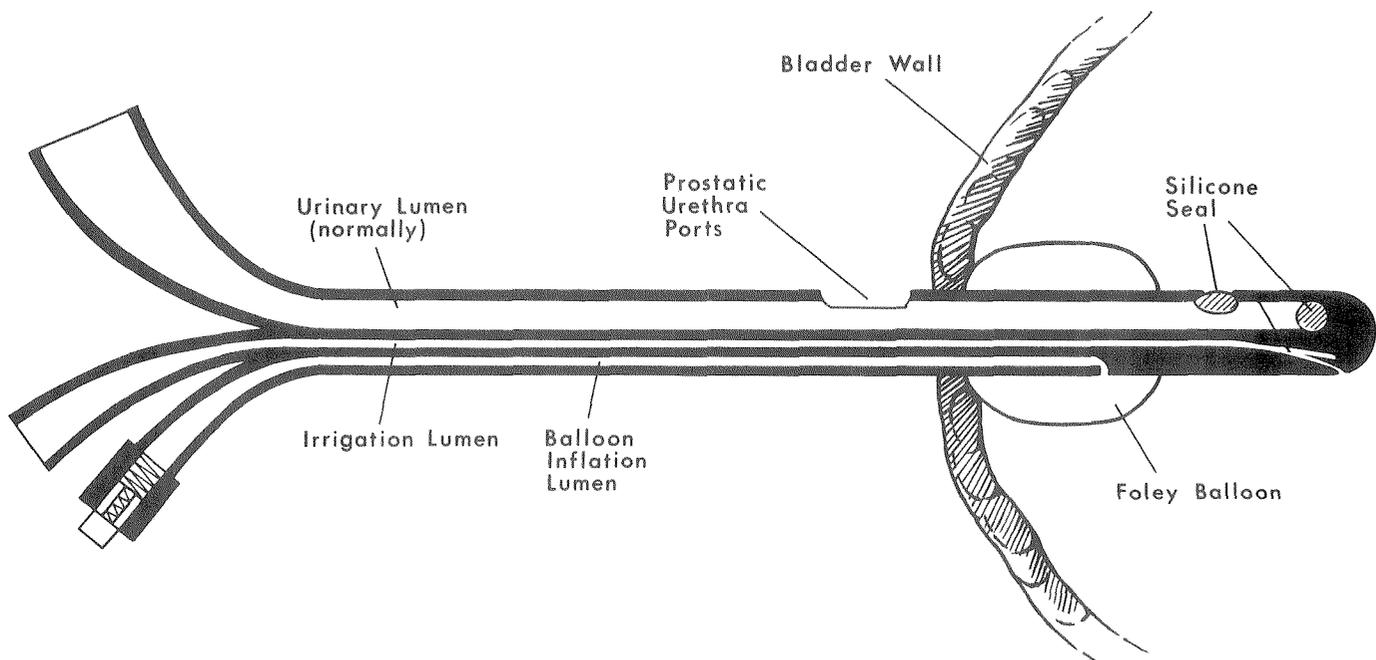
In most complete and nearly complete spinal cord injured males, if those spinal neural structures responsible for effecting ejaculation of semen are intact, ejaculation may be possible by rectal electrostimulation and/or by penile manipulation, but typically the seminal flow is directed into the bladder rather than antegrade to the exterior. Both exposure to acidic urine and dilution by the urine volume greatly reduced motility of the spermatozoa, even if the semen is quickly recovered from the bladder by flushing through a catheter, and subsequent centrifugation. Thus, recovering the semen in this manner for the ultimate purpose of artificial insemination would probably be futile. This is a frustrating dilemma, because many young men with such debilitating spinal cord injuries are desirous of fathering children with their marital partners.

While reflecting upon this problem it became clear that an instrument was needed which could be safely inserted into the penile urethra of such patients to divert semen



**Figure 5**  
Rectal electrostimulation probes.

from a retrograde to an antegrade flow without urine contamination. Commercially available Foley catheters were modified in several configurations to serve as an antegrade semen-collecting device. The inflatable balloon at the bladder end of this catheter acts as a ball-cock valve on the floor of the bladder to block urine flow from the bladder into the prostatic urethra, and semen from entering the bladder. At the present time we are employing a No. 18, siliconized rubber, 3-way Foley catheter modified as shown in **Figure 6**. The bladder ports in the urinary lumen are blocked with silicone rubber,



**Figure 6**  
Modified 3-way Foley catheter for collecting semen antegrade.

while the irrigation-lumen port and the Foley balloon-lumen port are left open. Ports, for allowing semen entrance into the urinary lumen, are cut into the lumen in that portion of the catheter residing in the prostatic urethra. We have experienced a moderate degree of success with this particular modification and will continue to explore its application in our studies.

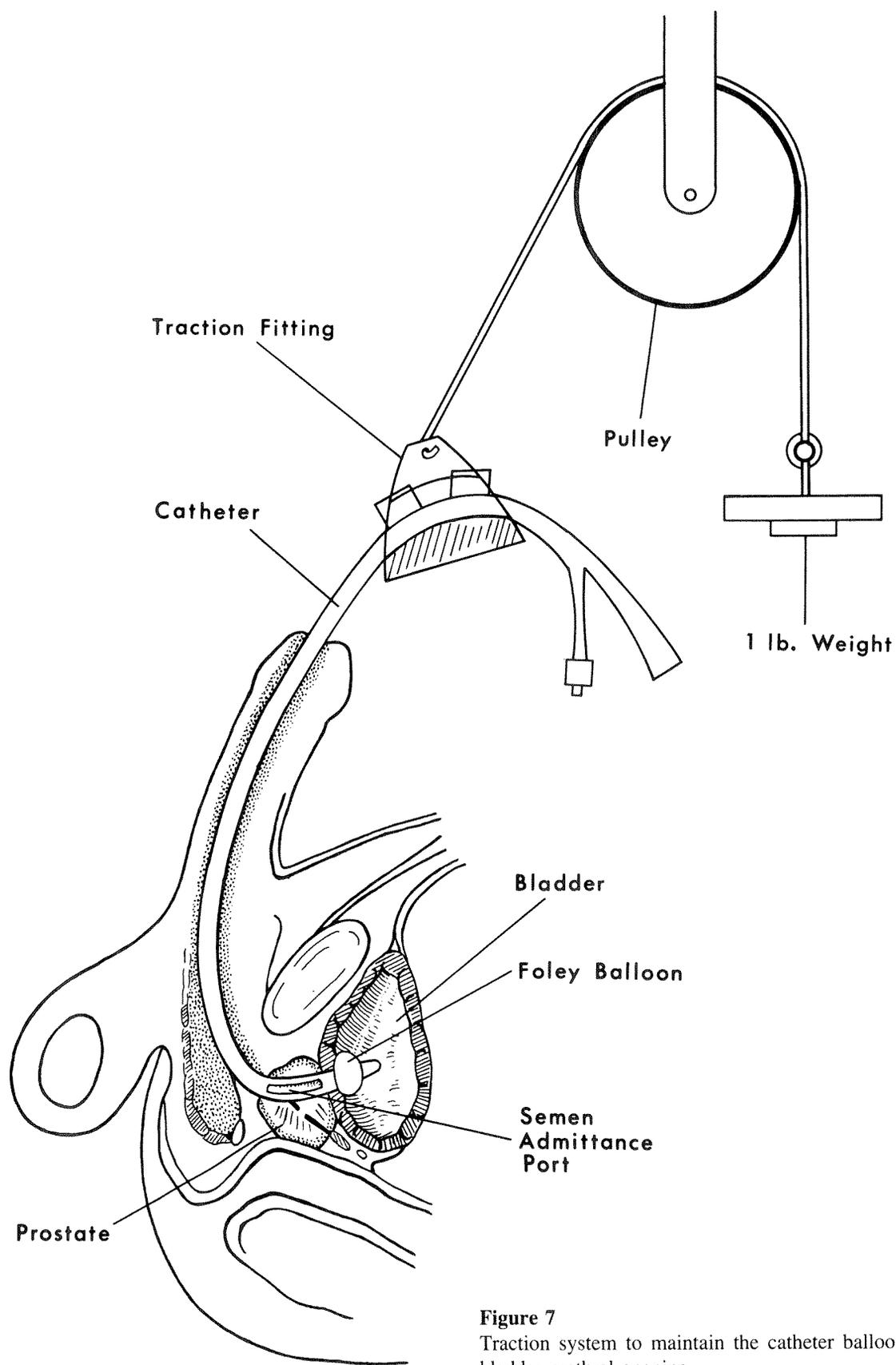
### Stimulation Procedure for Subjects

In a typical stimulation procedure the individual is appropriately draped and arranged in the dorsal lithotomy position on an examining table, with legs in stirrups for easy access to the rectum and genitalia. Proctosigmoidoscopy allows verification of an expected healthy rectal mucosa. After the sterile procedure the modified Foley catheter is inserted through the urethra and into the bladder. The balloon is inflated with sterile water to the required volume. To ensure that the balloon on the catheter is adequately sealing the bladder-urethral opening, a traction system (**Figure 7**) maintains a 1 lb pull (453.6 g) on the catheter.

The rectal stimulating probe is inserted and the electrode centers are placed in direct proximity to the region of the prostate gland, located by digital palpation prior to probe insertion. After ensuring that the maximum safe

current limit for that particular probe has been set into the instrument, the constant-current amplitude control on the front panel of the instrument is operated in a rhythmic, sinusoidal fashion with stepwise increase of the constant-current value, similarly to the protocol used in our earlier investigations with primates (16). At present the starting stimulus is 18 mA, with stepwise increments of 18 mA until the allowable limit of current is reached. Interface impedance initially ranges between 100 and 150  $\Omega$ , typically dropping to between 50 and 80  $\Omega$  as power delivery into the rectum warms surrounding tissues and reduces the various driving voltages. These voltages range between 1.8 and 2.1 initially, and typically increase to between 11 and 14 during maximum current delivery.

Verbalized descriptions by the patient of the stimulus sensation are recorded and combined with monitored values for constant-current and of voltage. Other physiological parameters, notably heart rate, blood pressure and scrotal-penile tumescence are also monitored and recorded. Discontinuation of stimulation occurs either when 1) a maximal tolerable current level is obtained (a value beyond which discomfort is too excessive to endure voluntarily), 2) maximally safe values are reached, or 3) emission from the urinary lumen of the catheter, or from the meatus, of a reasonably normal aliquot of semen is noted. Urine is withdrawn from the bladder via the irrigation lumen of the catheter and examined for the pres-



**Figure 7**  
Traction system to maintain the catheter balloon seal of the bladder urethral opening.

ence of sperm in order to determine how well the Foley balloon blocked the bladder opening. It should be noted that during the entire procedure the irrigation lumen allows access to the bladder for adding liquids, examining the contents, or exchanging the contents.

At the termination of the RPE procedure, proctosigmoidoscopy is repeated. In all of our work involving nonhuman primates as well as humans, using the electrical parameters described above, we have never observed more than a transient mild erythema to the rectal mucosa. After this procedure any semen collected is taken to the clinical laboratory and, using procedures described elsewhere (11), is examined for semen motility, sperm morphology, and count.

## CLINICAL RESULTS AND DISCUSSION

Using the RPE technology described herein, 31 paraplegic patients were studied with the purpose of effecting erection and seminal emission. The level of injury ranged between T2 and L3, and the extent of injury from clinically incomplete to complete. **Table 1** summarizes data obtained regarding electrical stimulus parameters, erection

(penile tumescence graded on a 1–10 scale with 10 representing full tumescence), and semen emission from 22 patients. These patients all had a sufficiently attenuated sensorium to permit current tolerance of 160 to 200 mA (0.29 to 0.36 mA/mm<sup>2</sup>), which in our system typically permits erection to occur. The other nine patients were relatively intolerant to such current delivery, and included predominantly patients whose injury level was below L1.

A more complete clinical documentation of these patients (testicular biopsy, serum hormone levels, urodynamic findings, semen analyses) has been published elsewhere (16). However, two observations from the data summarized in **Table 1** are of relevance here. First, since erection and ejaculation are two quite different physiological processes, both with important neurological components (11), RPE is variably effective in spinal cord injured patients depending on extent of neurophysiologic disruption. Thus, while patients Nos. 9 and 10 exhibited no erection but did produce seminal emission with RPE, patient No. 16 produced erection but not emission, and patient No. 22 produced neither. Patients Nos. 1 and 7 produced seminal emission, but erection was difficult to evaluate due to the presence of Small-Carrion penile im-

**Table 1**  
Electrical stimulation parameters, tumescence (erection) intensity, and direction of semen emission by RPE of spinal cord injured patients.

Patient	Injury Level	Tumescence Scale, 1–10	Electrical Stimulus Parameters				Semen Emission		
			current, mA	EMF, volts	impedance, Z ohms	density, mA/mm <sup>2</sup>	retrograde	catheter applied	antegrade
1	T2–3	implant	192	8	42	0.35	yes	yes	no
2	T4	3	190	10	53	0.35	yes	yes	yes
3	T4	3	170	10	58	0.31	yes	yes	no
4	T5	4	180	11.3	63	0.33	no	yes	yes
5	T5	4	162	9.8	60	0.29	yes	yes	yes
6	T6–7	4	196	12.6	64	0.36	yes	yes	yes
7	T7	implant	200	10	50	0.36	yes	no	no
8	T9	6	195	10.2	52	0.35	yes	yes	yes
9	T9	0	161	11	68	0.29	yes	yes	yes
10	T10	0	208	14	67	0.38	yes	yes	yes
11	T10–11	7	189	12	63	0.34	yes	yes	yes
12	T10–11	6	198	9.9	50	0.36	yes	yes	yes
13	T11–12	6	198	13.2	67	0.36	no	yes	yes
14	T11–12	4	198	14.7	74	0.36	yes	yes	yes
15	T12	8	200	13	65	0.36	yes	yes	no
16	T12	9	195	13.4	68	0.36	no	yes	no
17	T12	5	195	15.4	79	0.36	no	yes	yes
18	T12	9	196	14.8	76	0.36	yes	yes	yes
19	T12	9	195	12.5	64	0.36	yes	yes	no
20	T12–L1	9	180	17.6	98	0.33	yes	yes	no
21	T12–L1	5	196	12.5	64	0.35	no	yes	yes
22	L1	0	197	15.1	77	0.36	no	yes	no

plants. The remaining 16 patients produced both erection and emission. Second, in those patients who produced emissions by RPE (20 of 22), typically there was a combination of antegrade and retrograde semen flow. Our aim has been to consistently direct semen flow antegrade, so as to permit collection without dilution by bladder urine whose volume and acidity are both detrimental to maintaining sperm motility. Patient individuality makes achievement of such consistency difficult to obtain. Variable anatomic size of the urethra and bladder neck require selection of an appropriate Foley catheter and balloon inflation volume to block urine entry into the prostatic urethra. Also transurethral resection of the bladder sphincter

(TURS), done in many patients to improve voiding, varies in its extent, thus altering the effectiveness of a Foley catheter balloon in preventing semen contamination with urine.

## ACKNOWLEDGMENT

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