INFLUENCE OF ELECTRICAL STIMULATION ON SKELETAL MUSCLE SPASTICITY

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ABSTRACT

In a previous paper, Bajd[1] proposed a method of assessing spasticity of the quadriceps by using gravity to allow the leg to passively fall while recording the knee goniogram. This method was used to document spasticity of ten spinal cord injured patients on five consecutive days. The first three days measurements were used to establish variability of measurements taken 30 minutes apart. The last two days were used to establish the effect of 30 minutes of cyclical electrical neuromuscular stimulation of the quadriceps on spasticity as well as document changes 30 minutes following stimulation. Four patients demonstrated significant reduction in spasticity both immediately and 30 minutes following stimulation. Three patients showed both a decrease and increase between immediately and 30 minutes following stimulation. Three patients showed inconsistent results. A new technique of assessing spasticity using repetitive testing is also presented.

INTRODUCTION

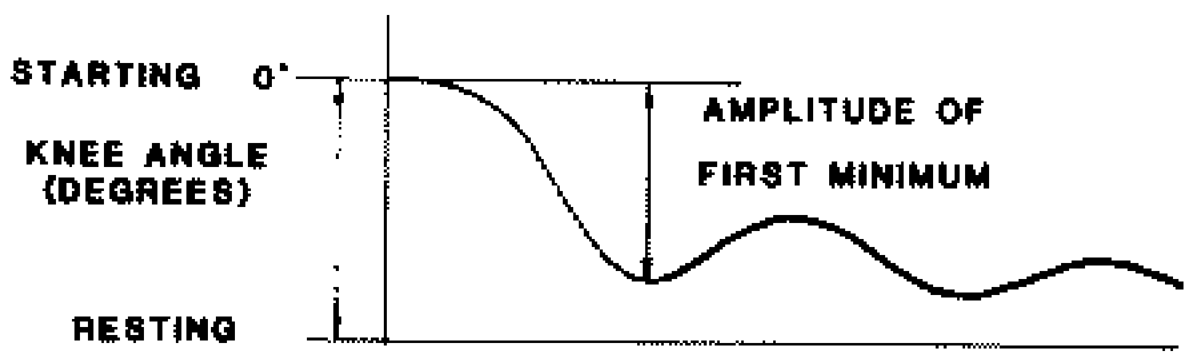
Between 5 and 6 million individuals in the United States have skeletal muscle spasticity[2] about at least one joint. There are three major approaches currently used as treatment procedures for spasticity: pharmacological, surgical and therapeutic modalities. One therapeutic modality, electrical neuromuscular stimulation, is regaining popularity primarily for its usefulness in muscle strengthening and neuromuscular re-education, however both basic animal research and clinical studies have shown that electrical stimulation can also have an effect on spasticity. Electrical stimulation of certain brain areas of decorticate animals increased rigidity while stimulation of other areas decreased or even abolished decorticate rigidity.[3] Clinical reports of electrically stimulated spinal cord injured[4,5,6] and hemiplegic[5] patients have claimed reduction in spasticity and muscle spasms with only few reports of heightened spasticity.[4]

Electrical stimulation has been used with incomplete paraplegic and quadriplegic patients at Rancho Los Amigos Hospital in order to strengthen their paralyzed quadriceps muscles. It has been reported through the subjective descriptions of these patients that in some cases spasticity decreases and in others increases following a program of cyclical stimulation. Since electrical neuromuscular stimulation using surface electrodes excites both motor and sensory pathways, and the stimulation of afferent fibers may produce post-tetanic potentiation at the monosynaptic connections on the alpha motoneurons, it is not unexpected that electrical stimulation may well aggravate spasticity[7] as well as inhibit it. The purpose of this study was to evaluate the effects of a cyclical neuromuscular stimulation program for the quadriceps on quadriceps spasticity in incomplete spinal cord injured patients using potentially more reliable means of assessing spasticity.

METHODS

Spasticity of the knee extensor muscles was tested as described in a preceding paper by Bajd, by placing the patient on a tilt table with both legs bent over the edge hanging free at the knee. The patient was asked to relax as much as possible. The examiner grasped the foot and brought one leg to a horizontal position. The limb was allowed to fall freely while recording knee angle with an electrogoniometer and recording the instant of release by using an ankle switch.

To estimate the degree of spasticity from the knee goniogram, a relaxation index was defined (Fig. 1) as the ratio of the first minimum angle reached by the falling knee (starting angle reference = 0 degrees) to the resting angle. The resting



NORMALIZED RELAXATION INDEX $R_n = \frac{\text{FIRST MINIMUM ANGLE}}{\text{RESTING ANGLE}} \div 1.6$

$0 < R_n < 1$ SPASTICITY

$R_n \geq 1$ NO SPASTICITY

Fig. 1. Definition of Normalized Relaxation Index Obtained From Knee Goniogram

angle is the knee joint angle of the resting leg prior to taking the measurement (referred to starting angle) and ranged from 50 degrees to 80 degrees. Measurements of normal subjects displayed relaxation values of 1.6. Consequently a normalized relaxation index was defined as Rn = R/1.6. A normalized relaxation index of 0 signifies no motion of the knee from the extended position and therefore extreme spasticity. A normalized relaxation index of 1 signifies a normal limb swing and therefore no spasticity. The values between 0 and 1 correspond to lessening degrees of spasticity.

Measurements were obtained from five patients in both lying and sitting positions. Results supported the contention that in the lying position the initial length of the rectus femoris muscles was increased allowing a more sensitive assessment of spasticity. Subsequent measurements were performed with the patient placed on his back on a tilt table.

The influence of electrical stimulation of the knee extensors on spasticity of the same muscle group was tested on ten spinal cord injured patients on five consecutive days. The measurements were performed in the morning before other physical therapy exercises. On the first three days, two measurements were performed with 30 minutes of rest between measurements. Three measurements were performed on the fourth and fifth days, 30 minutes apart. Cyclic electrical stimulation was applied to knee extensor muscles for the 30 minutes between the first two measurements on the fourth and fifth days. The cycle times of stimulation were 6 seconds of stimulation followed by 12 seconds of rest. Stimulation frequency was 33 Hz with a pulse duration of 0.3 ms. The electrical stimulation exercise was isotonic.

RESULTS

Nine of the ten patients participating in the program were incomplete paraplegic and quadriplegic patients (Table I). One patient was a complete injury. The reasons for the accident were in most cases gunshot wounds (GSW) or motor vehicle accidents

Table I. General patient data

No.	Init.	Sex	Age	Lesion	Accident	Months Post-Injury	FES Treatment
1	D.D.	M	27	T6 inc	Tumor	3-1/2	No
2	G.L.	M	42	T3 inc	GSW	42	No
3	A.O.	M	31	C5 inc	MVA	4-1/2	No
4	E.R.	M	22	T5 inc	GSW	1	No
5	R.S.	M	19	C5 inc	GSW	2	Yes
6	T.T.	M	51	C5-6 inc	Work Accident	21	No
7	R.S.*	M	27	C7-8 comp	MVA	4	No
8	M.H.	M	25	T7 inc	GSW	1-1/2	No
9	C.P.	F	33	C2-3 inc	MVA	4-1/2	No
10	L.D.	M	11	T5 inc	GSW	3-1/2	No

(MVA). All but two of the patients were less than 4-1/2 months after their spinal cord injury when tested. The other two patients were 21 and 42 months post-injury. All but one patient was excluded from all FES treatment until the conclusion of the spasticity testing.

A comparison of the normalized relaxation indexes for five patients in the lying and sitting positions is shown in Table II. A significant increase in the relaxation index was observed in four of the five patients when tested while sitting. All subsequent testing was performed with patients lying.

Table II.

	R_n	
patient	lying	sitting
J.W.	.68	.99
C.L.	.46	.69
D.M.	.64	.79
E.R.	.47	.39
R.S.	.46	.62

Figure 2 shows the normalized relaxation index of four patients demonstrating decreases in spasticity following FES. All four of the patients showed increased relaxation on the first three days when no stimulation was applied. This is not unexpected as the patients were lying relaxed on a table for 30 minutes. Solid lines on the fourth and fifth days correspond to measurements before and after electrical stimulation, while the dotted lines represent the 30 minutes of rest after the stimulation session. In most cases, the reductions in the degree of spasticity are noticeably greater following stimulation than that observed following rest on the first 3 days. In most cases further relaxation occurred 30 minutes after cessation of stimulation. It is also interesting to mention that the patient A.O. claimed that the stimulation relieved his spasticity for the entire fifth day which was demonstrated by measurements taken that day (Fig. 2d).

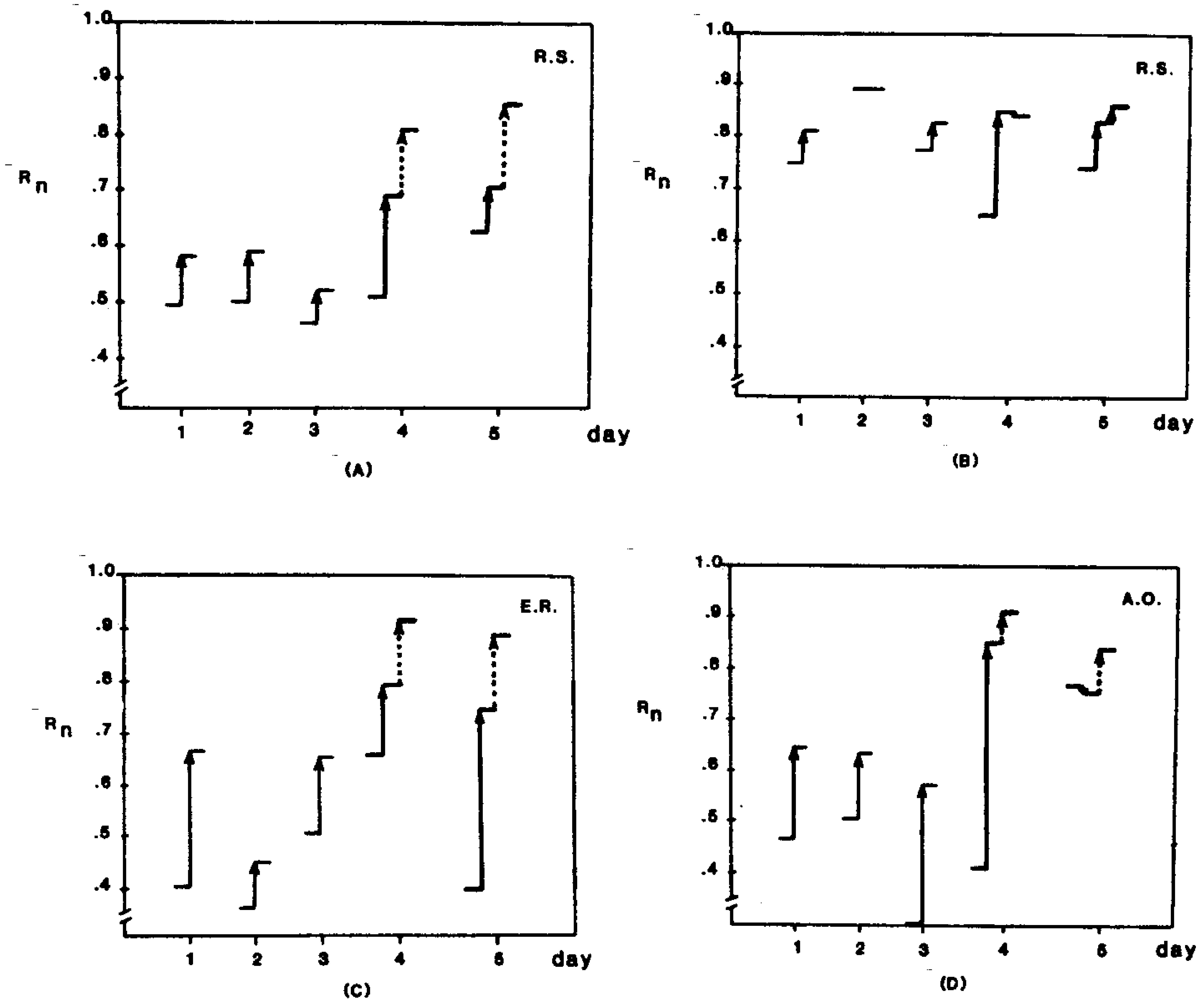


Fig. 2. Noticeable decrease of spasticity following FES as observed in four patients.

Figure 3 shows three patients who demonstrated small increases in spasticity following FES. One of these patients (Fig. 3a) also showed a tendency to increase in spasticity following 30 minutes rest on the first three days. Two patients, C.P. and D.D., (Figs. 3a, b) showed an increase in spasticity immediately following the 30 minute stimulation session on the fourth and fifth days and the same patients showed decreased spasticity 30 minutes after cessation of stimulation. The third patient, L.D., (Fig. 3c) showed slight decreases in spasticity immediately following the stimulation session and increases 30 minutes following the cessation of stimulation on both stimulation days.

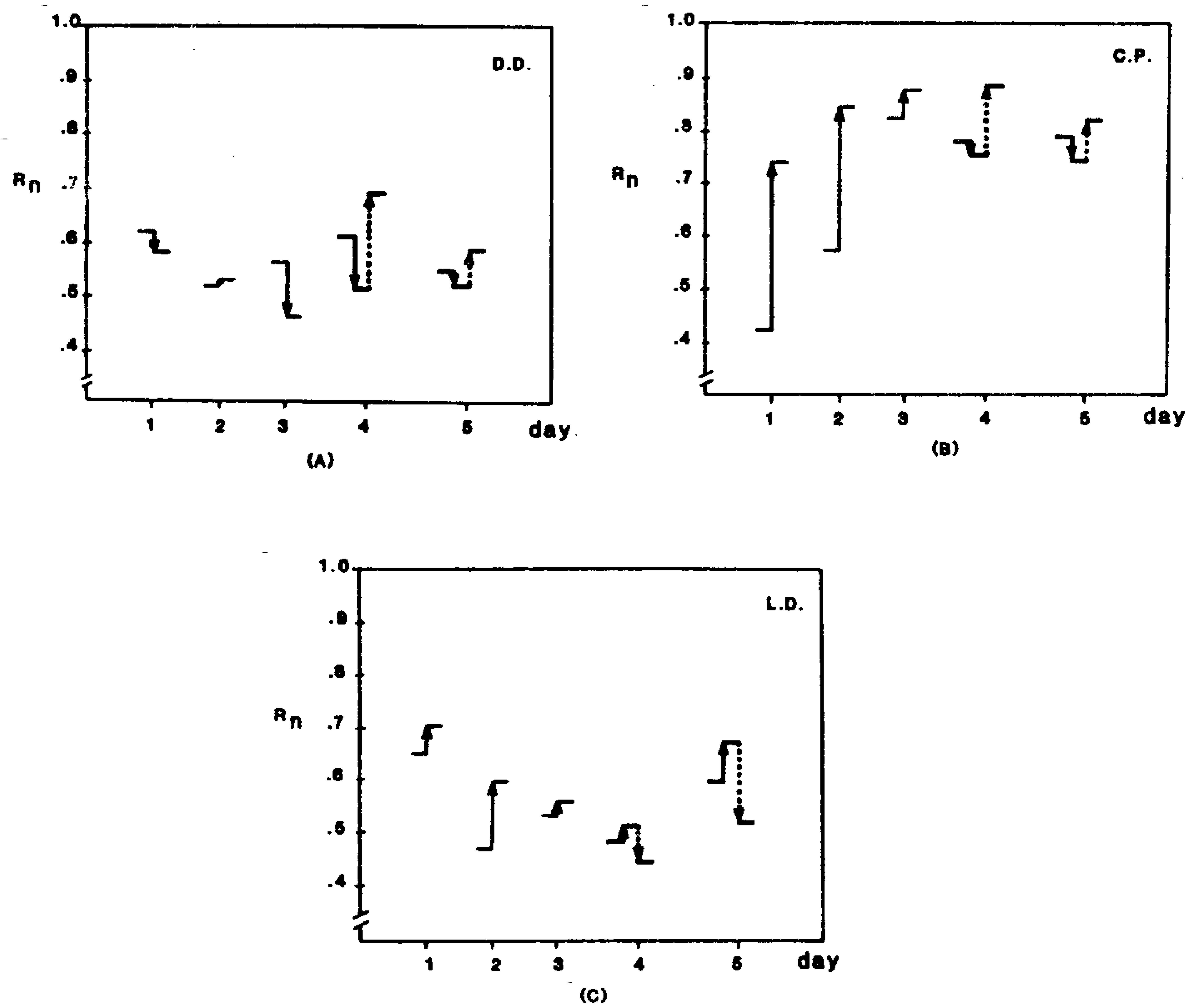


Fig. 3. Increase of spasticity following FES.

Inconsistent results were obtained with the last three patients. Some reasons for this inconsistency are attributable to outside factors. Patient M.H. (Fig. 4a) took medication to reduce stomach pains in the morning of the second day. Patient T.T. (Fig. 4b) was an outpatient and had a glass of wine before coming to the hospital on the fifth day. In both cases spasticity was considerably reduced. Such variability in measurement of spasticity have been reported by others as well.[5]

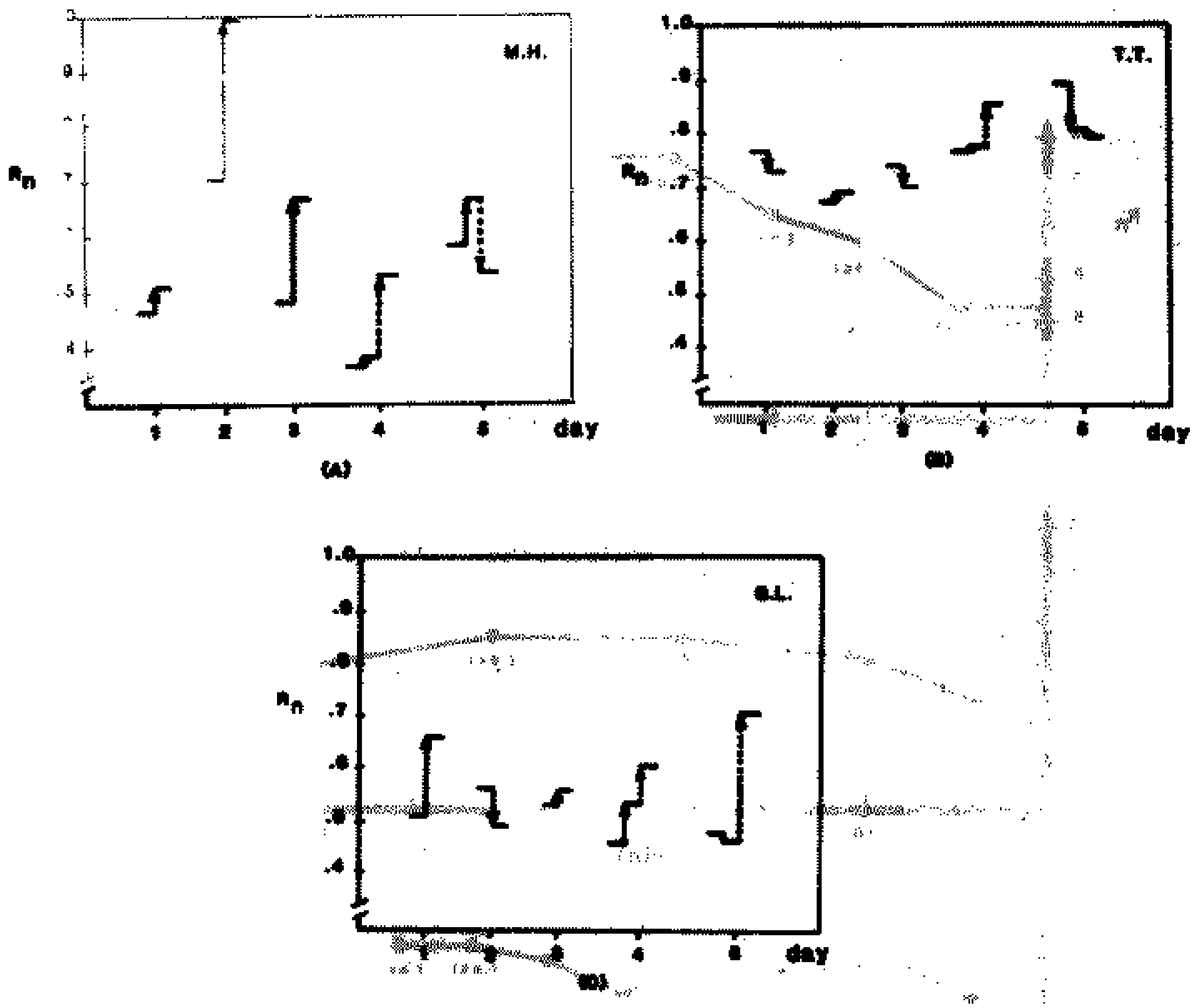


Fig. 4. Inconsistent results as obtained with three patients.

REPETITIVE TESTING

A test was made to determine fluctuations in the measurements due to repetitive testing. Measurements were taken each 5 minutes for forty minutes, each 10 minutes for forty minutes and each minute for ten minutes during three consecutive days. The results obtained on one of the five patients are shown in Figure 5. For each of the three different repetition rates, a plateau of the relaxation index was reached. During repetitions each 5 minutes (Fig. 5a) and 10 minutes (Fig. 5b), the plateau was attained after approximately 20 minutes. When the time between repetitions was only 1 minute (Fig. 5c), the plateau was reached by the third minute. At fast repetitions of the measurements the test itself is influencing the next tests

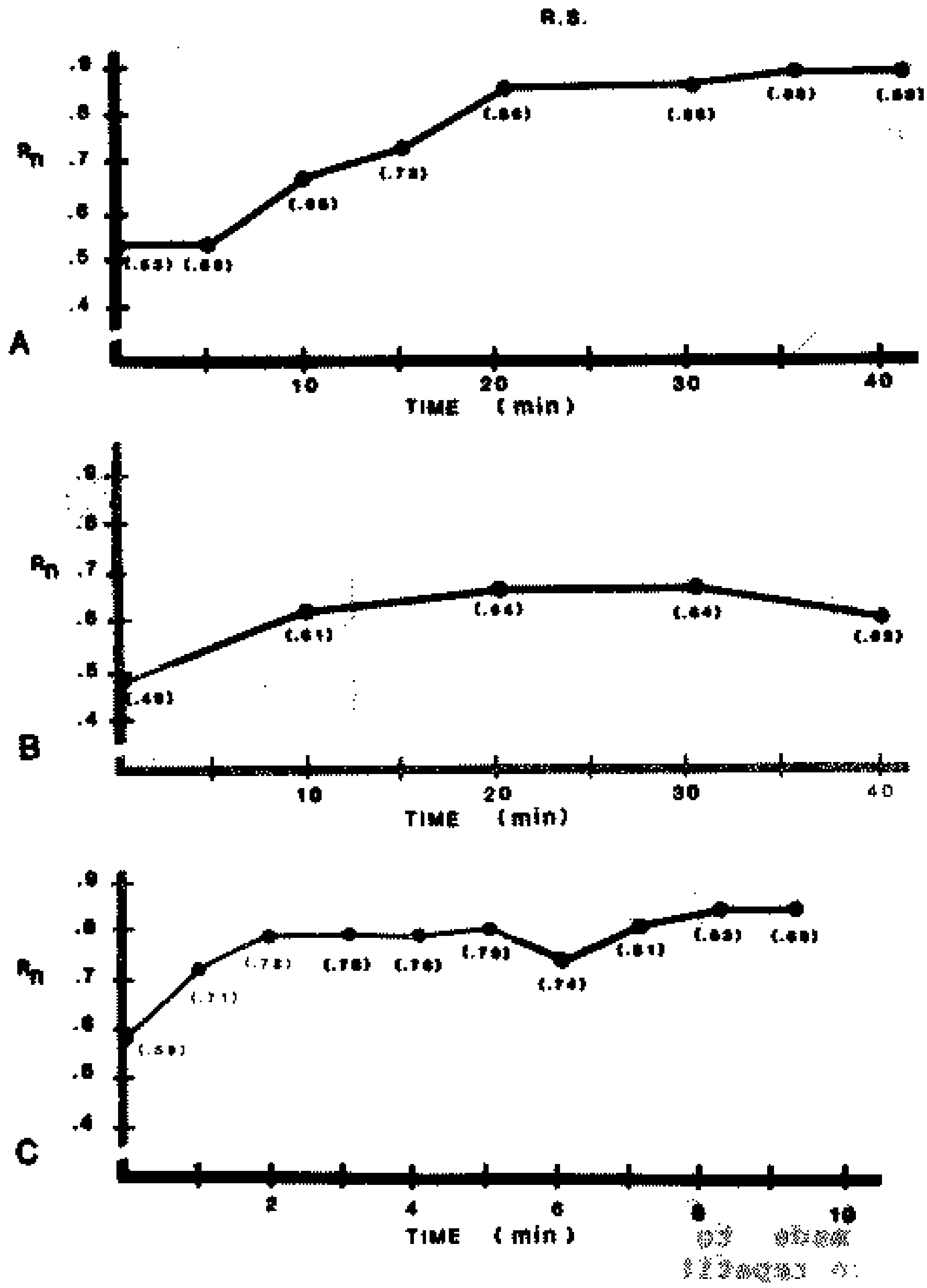


Fig. 5. Changes in relaxation index when repeating the spasticity test each 5 minutes, 10 minutes, and 1 minute.

and the degree of spasticity is lessened. Quickly repeating spasticity testing may provide more reliable data than performing only one test.

Three spasticity variables can be extracted from the repetitive testing data: 1) the initial value of the relaxation index, 2) the value of the steady state plateau, and 3) the rise time between the first measurement and the plateau.

DISCUSSION

A significant decrease of spasticity was observed in four patients. Slight increases immediately following stimulation but decreases 30 minutes later was observed in two patients and increases 30 minutes after stimulation in one patient. In the other three patients no consistent influence of stimulation on spasticity was observed. Although the population studied was limited in numbers, it can be concluded that patients' spastiticy varied from day to day and the effects of stimulation can be unpredictable. The trend, however, was probably toward a reduction in spasticity following electrical stimulation.

One of the greatest problems in trying to assess spasticity is the fact that any method or test used in itself affects the measure of any subsequent tests. Consequently, if more than one test or trial is used, each will yield a different result. If only one test is made, the result can vary widely depending on previous activity or inactivity, or the time of day.

An effort was made in the repetitive tests to observe the effects of multiple testing in hopes that if performed often enough, a steady state measure would be reached which would not be so sensitive to previous activity or to the test itself.

Further study of the repetitive testing method is necessary to verify just how well it can measure the "basic" level of spasticity. In addition, the influence of electrical stimulation on antagonist muscle spasticity and the effect of stimulation on functionally allied spastic muscle groups at other joints require future efforts. The impact of electrical stimulation on skeletal muscles hypertonia using different parameters and while applying it to different patients, such as those suffering from stroke, multiple sclerosis, Parkinson's disease or cerebral palsy also needs further investigation.

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