

Resistive Inspiratory Muscle Training: Its Effectiveness in Patients With Acute Complete Cervical Cord Injury

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ABSTRACT. Liaw M-Y, Lin M-C, Cheng P-T, Wong M-KA, Tang F-T. Resistive inspiratory muscle training: its effectiveness in patients with acute complete cervical cord injury. *Arch Phys Med Rehabil* 2000;81:752-6.

Objective: To evaluate if resistive inspiratory muscle training (RIMT) can improve lung function in patients with complete tetraplegia within half a year after trauma.

Design: A prospective study. The experimental patients received training with a Diemolding Healthcare Division inspiratory muscle trainer for 15 to 20 minutes per session, twice per day, 7 days a week for 6 weeks.

Setting: Hospital-based rehabilitation units.

Patients: Twenty patients who were in their first 6 months of complete cervical cord injury were randomly enrolled into RIMT (10 patients) and control (10 patients) groups.

Main Outcome Measure: Spirometry, lung volume test, maximal inspiratory pressure, maximal expiratory pressure, and modified Borg scale measurements at rest were performed before training and at the end of 6 weeks of training.

Results: Most of the pulmonary parameters showed statistically significant improvements within the RIMT and control groups, but the improvements were greater in the RIMT group. In addition, the improvements in total lung capacity, total lung capacity predicted percentage, vital capacity, minute ventilation, forced expiratory volume in 1 second predicted percentage, and the resting Borg scale in the RIMT group showed significantly greater improvement.

Conclusion: RIMT can improve ventilatory function, respiratory endurance, and the perceived difficulty of breathing in patients with complete cervical spinal cord injury within half a year after trauma.

Key Words: Breathing exercises; Tetraplegia; Spinal cord injuries; Resistive inspiratory muscle training; Respiratory function; Rehabilitation.

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RESPIRATORY COMPLICATIONS are major causes of morbidity and mortality in persons with tetraplegia. The greatest increase in mortality occurs in the first 6 months to 1 year after trauma. After the first 1 to 2 years, the mortality curve parallels that of normal individuals.^{1,2} Respiratory problems in tetraplegic patients may result from a loss of control of the

abdominal muscles, the intercostal muscles, and, in some cases, a partial or total loss of the diaphragmatic function.³

Leith and Bradley⁴ showed that normal subjects could improve their ventilatory muscle strength and endurance with a specific training program of repeated static maximal inspiratory and expiratory maneuvers against obstructed airways. In tetraplegic patients, several different techniques of resistive inspiratory muscle training (RIMT) have been used to improve ventilation, ventilatory muscle strength, and endurance to prevent secretion retention and other lung complications, including pneumonia and atelectasis.⁵⁻¹²

Fugl-Meyer⁵ and Hultgren and associates⁶ reported that in patients with acute or chronic traumatic complete spinal cord injury (SCI), ventilatory function, maximal respiratory pressure, and maximal voluntary ventilation were improved by insufflation of air, using a pump, and performing forced voluntary expirations and inspirations against a resistance. Gross and colleagues⁷ reported on a RIMT program—with sessions of 30 minutes daily, 6 days a week, for 6 chronic tetraplegics patients—that showed increased inspiratory mouth pressure, decreased diaphragmatic fatigue, or an increase in high to low electromyogram amplitude and improvement of dyspnea. Hornstein and Ledson⁸ documented improvements in inspiratory muscle strength and endurance, and reported shortness of breath using a graded resistor in two cases of acute quadriplegia. Loveridge and associates⁹ also obtained similar results in patients with C6-C7 traumatic complete motor quadriplegia at least 1 year after injury. In the study, the subjects were assigned either to a training or a control group. Rutchik and colleagues¹⁰ reported that regular inspiratory muscle training in subjects with chronic complete or incomplete cervical SCI may result in decreased restrictive ventilatory impairment and reported dyspnea. Biering-Sorensen and associates¹¹ reported that peak expiratory flow was improved by using a respiratory muscle training mouth-nose mask, with a fixed expiratory and an increasing inspiratory resistance, for chronic tetraplegics. Derrickson and coworkers¹² compared the effectiveness of RIMT with that of abdominal weight training in patients with acute complete quadriplegia, but the data did not support the effectiveness of one method of training over the other.

The training sessions of the above-mentioned studies were typically limited to 15 to 30 minutes each, with 2 to 3 sessions a day, 5 to 7 days a week, for a total period ranging from 6 to 8 weeks.⁵⁻¹² In addition, these studies were conducted in patients with acute or chronic, traumatic complete or incomplete tetraplegia, but there have been only two studies that had been restrictively conducted in the early stages of SCI.¹² Furthermore, there has not been a well-designed, randomized study with a control group to determine conclusively the benefit of the RIMT protocol. The purpose of this study was to determine whether a RIMT program using the Diemolding Healthcare Division (DHD) resistance trainer^a is beneficial to patients with complete cervical cord injury within the first half year after trauma.

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METHODS

Subjects

Thirty patients with traumatic complete tetraplegia, Frankel A, at levels between C4 and C7, as defined by the American Spinal Injury Association standards, were eligible for the study. They were randomly assigned into either the control or the RIMT group with 13 and 17 subjects in each group, respectively. In the control group, two patients dropped out due to lung infection and one patient was transferred to another hospital because he lived far away from our hospital; in the RIMT group, two patients discontinued training due to pneumonia, one patient because of recurrent urinary tract infection, one patient improved to incomplete SCI after 6 weeks of training, and three patients gave up the trial because of dizziness, fatigue, or boredom while using the modality.

Twenty patients completed the study, with two women and eight men in each group. During the period of study, all were admitted to the rehabilitation department at Chang Gung Memorial Hospital with duration of injury of less than half a year (30 to 120 [mean \pm SD = 63.1 \pm 31.4] days) after injury in RIMT group; 32 to 134 (mean \pm SD = 66.3 \pm 38.4) days in the control group. The age range was 16 to 49 (mean \pm SD = 30.9 \pm 11.6) years in the RIMT group, and 17 to 52 (mean \pm SD = 36.5 \pm 11.5) years in the control group. There was no significant difference in comparison of age and duration since injury between the experimental and control group (table 1). None of the patients had a previous history of lung disease, signs of respiratory disease, cardiovascular problems, metabolic problems, orthopedic problems, head injuries,

mental illness, or other deficiencies. The chest radiograms done before entering the program were normal.

Methods

The subjects in the experimental group received the daily course of RIMT using a DHD inspiratory muscle trainer.³ Concurrently, other rehabilitative programs such as passive range of movement, mattress exercise, sitting balance, or upper limb functional training were not withheld from either group.

The inspiratory muscle trainer, with a total of six different levels of resistance (blue, yellow, green, light-blue, white, and red; with diameters of 7, 6, 5, 4, 3, and 2mm, respectively), were used. All subjects in the RIMT group during training were positioned either supine or with their heads 10° to 15° up, and were required to wear mouthpieces and nasal clips.

The training started with the inspiratory trainer set at the smallest inspiratory resistance setting (blue, 7mm). If the patient felt uncomfortable during training, the inspiratory muscle trainer was used for intermittent periods of training and resting (training to rest ratio was 3:1). The breathing rate was controlled to about 12 to 16 breaths per minute. The period of the inspiratory muscle training was 15 to 20 minutes, twice a day, 7 days a week. Once training sessions could be easily carried out at a particular resistance setting for an additional 3 days, the resistance was increased, ie, the inspiratory diameter was decreased by 1mm to the next sequential color level. If the training sessions could not be completed with this increased resistance, the last part of the session was performed with the previous resistance setting.

Table 1: Physical Characteristics of Resistive Inspiratory Muscle Training and Control Subjects

Subject	Age (yrs)	Sex	Height (cm)	Weight (kg)	Duration of Injury (days)	Neurologic Motor Level		Initial Tracheostomy (+/-)	Previous Pneumonia (+/-)	Smoking (+/-)
						Right	Left			
RIMT										
1	25	M	175	53	35	C4	C5	-	-	-
2	43	M	165	50	90	C5	C5	-	-	+
3	16	F	165	50	99	C4	C4	-	-	-
4	41	F	150	46	42	C7	C4	-	-	-
5	17	M	165	52	38	C6	C6	-	-	-
6	33	M	165	50	120	C5	C5	+	+	-
7	32	M	170	75	30	C6	C5	-	+	-
8	18	M	167	51	65	C4	C4	-	-	-
9	35	M	160	55	73	C4	C4	-	-	-
10	49	M	168	60	39	C6	C6	-	-	-
Mean	30.9		165.0	54.2	63.1					
SD	11.6		6.6	8.2	31.4					
Control										
1	38	M	170	82	32	C7	C7	-	-	-
2	52	F	156	65	78	C5	C6	-	-	-
3	37	M	164	57	38	C6	C6	-	-	+
4	45	M	165	50	54	C4	C4	-	-	-
5	29	M	180	68	134	C5	C5	-	-	-
6	49	M	167	60	126	C5	C4	-	-	-
7	17	F	168	52	41	C5	C5	-	-	-
8	45	M	158	65	36	C5	C5	-	-	-
9	27	M	170	54	37	C5	C5	-	-	-
10	26	M	176	65	87	C4	C5	-	-	-
Mean	36.5		167.4	61.8	66.3					
SD	11.5		7.3	9.4	38.4					
t value	.29		.45	.07	.84					

Data are presented as mean \pm SD. There was no significant difference between the RIMT group and the control group for any variable.

Before and after the scheduled 6 weeks of respiratory training, the following lung function parameters were measured: cough evaluation,³ which was graded as "functional," "weak-functional," or "nonfunctional"; maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), spirometry, and lung volume test.

All patients had weak-functional coughs. The spirometry was performed with an automated body plethysmograph,^b using American Thoracic Society standards.¹³ Chest mobility was measured at levels of the axilla, xyphoid process, and 2cm above the umbilicus.³

The MIP and MEP were checked with a mouth pressure meter^c while each subject was seated and wearing a nose-clip. The MEP was measured near total lung capacity (TLC) after a maximal inspiration. The MIP was measured near residual volume (RV) after a maximal expiration. The pressures measured were maintained for at least 1 second. The determinations were repeated until two technically satisfactory measurements were recorded, and the highest value was used in subsequent calculations.¹⁴ The resting dyspnea was quantified before training and at the end of 6 weeks of training by use of the modified Borg scale.¹⁵

Data Analysis

The physical characteristics of the RIMT and control subjects were analyzed by unpaired *t* test. The improvement ratio (IR) was calculated as (posttraining - pretraining)/pretraining, and was described as a percentage. Continuous variables of parameters of pulmonary function and respiratory muscle strength were given as mean \pm SD, prestudy to poststudy comparisons were made using paired *t* tests, and group comparisons were made using unpaired *t* tests. A paired *t* test was used to compare the differences in change of chest circumference between inspiration and expiration before and after training in each. The level of significance was set at $p < .05$ for all analyses. All statistical analyses were performed using the SPSS statistical package.^d

RESULTS

There were no significant differences between the RIMT group and the control group for any physical characteristics (table 1). A summary of pulmonary functions and the respiratory muscle strength measurements taken before the study and at the end of 6 weeks are presented in tables 2 and 3. There were statistically significant differences in functional vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), MIP, MEP, Borg scale measurements, vital capacity (VC), and RV/TLC between pretraining and posttraining results within both groups. There were significant differences in FVC predicted percentage (FVC% predicted), FEV₁ (% predicted), peak expiratory flow (PEF), PEF (% predicted), VC (% predicted), TLC, and TLC (% predicted) only in the RIMT group. In addition, there were significant differences ($p < .05$) in the improvement ratio of FEV₁ (% predicted) (63% \pm 53% in the RIMT group vs 21% \pm 33% in the control group); TLC (21% \pm 16% in the RIMT group vs 3% \pm 17% in the control group), TLC (% predicted) (21% \pm 11% in the RIMT group vs -1% \pm 20% in the control group), VC (% predicted) (76% \pm 62% in the RIMT group vs 21% \pm 32% in the control group), minute ventilation (VE) (24% \pm 41% in the RIMT group vs -27% \pm 20% in the control group), and Borg scale measurements (-22% \pm 4% in the RIMT group vs -11% \pm 9% in the control group) between both groups. There were no significant differences in the improvement ratios of the MIP (29% \pm 21% in the RIMT group vs 27% \pm 27% in the control

Table 2: Mean Prestudy and Poststudy Pulmonary Results and Percentage Changes for RIMT and Control Groups

Groups Parameters/ Time	RIMT	Control	<i>p</i>
FVC (L)			
Prestudy	1.2 \pm 0.4*	1.5 \pm 0.6*	.225
Poststudy	1.8 \pm 0.4	1.9 \pm 0.9	.639
IR (%)	66 \pm 74	28 \pm 36	.172
FVC (% predicted)			
Prestudy	32.8 \pm 8.8*	41.9 \pm 15.5	.122
Poststudy	50.1 \pm 10.9	49.9 \pm 19.0	.981
IR (%)	64 \pm 61	21 \pm 32	.061
FEV ₁ (L)			
Prestudy	1.1 \pm 0.3*	1.3 \pm 0.6*	.232
Poststudy	1.6 \pm 0.4	1.7 \pm 0.8	.714
IR (%)	63 \pm 67	29 \pm 36	.168
FEV ₁ (% predicted)			
Prestudy	35.2 \pm 9.0*	45.5 \pm 16.0	.093
Poststudy	54.9 \pm 14.1	54.2 \pm 20.1	.93
IR (%)	63 \pm 53	21 \pm 33	.045†
FEV ₁ /FVC (%)			
Prestudy	91.2 \pm 6.6	89.0 \pm 6.2	.468
Poststudy	91.0 \pm 7.2	89.6 \pm 8.1	.687
IR (%)	0 \pm 9	1 \pm 9	.871
PEF (L/sec)			
Prestudy	2.5 \pm 0.4*	3.0 \pm 0.7	.074
Poststudy	3.5 \pm 1.1	3.9 \pm 1.9	.596
IR (%)	39 \pm 36	23 \pm 40	.384
PEF (% predicted)			
Prestudy	36.9 \pm 9.0*	42.3 \pm 11.6	.261
Poststudy	52.5 \pm 19.6	50.8 \pm 22.1	.858
IR (%)	41 \pm 37	20 \pm 40	.226
MIP (cmH ₂ O)			
Prestudy	45.4 \pm 10.3*	50.9 \pm 14.0*	.368
Poststudy	58.6 \pm 16.7	63.1 \pm 17.9	.599
IR (%)	29 \pm 21	27 \pm 27	.844
MEP (cmH ₂ O)			
Prestudy	27.8 \pm 4.7*	28.4 \pm 5.0*	.794
Poststudy	39.7 \pm 18.8	40.9 \pm 8.9	.882
IR (%)	42 \pm 52	44 \pm 21	.915
Borg scale			
Prestudy	13.3 \pm 0.7*	13.4 \pm 0.8*	.723
Poststudy	10.4 \pm 0.7	12.0 \pm 1.2	.003
IR (%)	-22 \pm 4	-11 \pm 9	.002†

* Significant difference ($p < .05$) of paired *t* test between prestudy and poststudy values.

† Significant difference ($p < .05$) of unpaired *t* test between RIMT and control group.

group) or MEP (42% \pm 52% in the RIMT group vs 44% \pm 21% for the control group) between both groups.

There were statistically significant differences between the changes of the different poststudy chest circumference measurements only in the RIMT group (table 4).

DISCUSSION

Shaffer and colleagues¹⁶ estimated that the diaphragm is responsible for two thirds of respiration while a patient is sitting and three fourths while the patient is supine. Intercostal muscles relieve the diaphragm in times of fatigue and aid with expansion of the rib cage; accessory muscles of respiration, the scaleni, the sternocleidomastoid, and the abdominal muscles only play a minimal role in normal respiration.

The profile of pulmonary functional tests of individuals with complete tetraplegia is typically that of a restrictive ventilatory

Table 3: Mean Prestudy and Poststudy Pulmonary Results and Percentage Changes for RIMT and Control Groups

Groups Parameters/ Time	RIMT	Control	<i>p</i>
VC (L)			
Prestudy	1.2 ± 0.4*	1.5 ± 0.6*	.352
Poststudy	2.0 ± 0.5	1.9 ± 0.9	.840
IR (%)	78 ± 75	28 ± 36	.077
VC (% predicted)			
Prestudy	34.7 ± 11.4*	41.9 ± 15.5	.268
Poststudy	56.2 ± 12	49.9 ± 19.0	.404
IR (%)	76 ± 62	21 ± 32	.024†
TLC (L)			
Prestudy	3.8 ± 0.5*	3.9 ± 1.0	.770
Poststudy	4.6 ± 0.6	4.0 ± 1.0	.194
IR (%)	21 ± 16	3 ± 17	.048†
TLC (% predicted)			
Prestudy	83.1 ± 14.2*	80.1 ± 14.8	.69
Poststudy	100.0 ± 17.7	77.1 ± 9.0	.008
IR (%)	21 ± 11	-1 ± 20	.014†
RV (L)			
Prestudy	2.6 ± 0.4	2.3 ± 0.6	.262
Poststudy	2.6 ± 0.4	1.9 ± 0.4	.003
IR (%)	2 ± 16	-13 ± 23	.151
RV (% predicted)			
Prestudy	230.9 ± 83.8	172.7 ± 55.4	.136
Poststudy	231.7 ± 74.7	135.0 ± 28.0	.006
IR (%)	3 ± 19	-16 ± 26	.115
RV/TLC (%)			
Prestudy	68.3 ± 9.0*	59.0 ± 9.5*	.064
Poststudy	57.1 ± 6.6	49.6 ± 9.4	.08
IR (%)	-15 ± 14	-16 ± 15	.964
FRC (L)			
Prestudy	2.9 ± 0.4	2.7 ± 0.6	.631
Poststudy	2.9 ± 0.3	2.6 ± 0.7	.279
IR (%)	2 ± 17	-6 ± 13	.32
FRC (% predicted)			
Prestudy	119.4 ± 34.4	105.1 ± 19.4	.343
Poststudy	116.8 ± 26.0	92.0 ± 8.7	.031
IR (%)	1 ± 18	-10 ± 15	.207
VE (L/min)			
Prestudy	10.3 ± 3.9	13.9 ± 2.9*	.076
Poststudy	12.2 ± 4.7	9.9 ± 3.3	.282
IR (%)	24 ± 41	-27 ± 20	.014†

* Significant difference ($p < .05$) of paired *t* test between prestudy and poststudy values.

† Significant difference ($p < .05$) of unpaired *t* test between RIMT and control groups.

deficit. The TLC is reduced, the RV is increased. Persons with complete tetraplegia usually also have lost the majority of expiratory reserve volume because of paralysis of their expiratory musculature. As a result, their MEP is markedly reduced. The VC approximates their inspiratory capacity, and the MIP is

reduced. The maximal voluntary ventilation is also reduced. The work of breathing is increased and the diaphragm is prone to fatigue, particularly in those patients with high cervical cord injury.¹⁷⁻²⁰ Therefore inspiratory training is very important for individuals with complete cervical cord injury.

In our study, the results for the change between initial and posttraining arterial blood gases (ABGs) were also unremarkable (data not shown). It might be that the subjects were in a stable condition after SCI. These findings were similar to the study of Loveridge and colleagues,⁹ which demonstrated that all tetraplegics had normal ABG values.

In our previous study,²¹ we examined 50 cervical SCI patients. They were divided into two groups: 26 cases were divided into a group of patients with complete motor paralysis (Frankel A or B) and another group of patients with incomplete motor function (Frankel C or D). Pulmonary function testing was performed at 1-, 6-, and 12-month intervals after cervical cord injury. The results showed that the improvement of pulmonary function was greater in patients in their first 6 months post-trauma as compared with that during the second 6 months. This emphasizes the importance of inspiratory muscle training in the acute stage of SCI.

Ledsome and Sharp¹⁹ documented that a significant increase in VC occurred within 5 weeks of injury with an approximate doubling of VC 3 months after injury in patients with complete transections of the spinal cord at levels C4, C5, and C6. And the expiratory flow rates were directly dependent on VC.

The inspiratory-respiratory pressure is commonly reduced in high cervical cord injury, but tends to improve over time. In our study, although the MIP and MEP were significantly increased after 6 weeks of training in each group, there was no significant difference in the IR between the RIMT and the control groups. It could be that the number of patients was not large enough or that the duration of training was not long enough.

Crane and associates²² reported that the mean FVC for subjects not developing complications was 1865 ± 850mL as compared with those developing complications who averaged 1127 ± 410mL. Therefore they concluded that FVC was an important predictor of respiratory difficulties.²² In our study, the prestudy FVC in the control group was 1460 ± 620mL and the poststudy FVC was 1900 ± 910mL. The IR was 28% ± 36%. And in the RIMT group, the pretraining FVC was 1180 ± 370mL, and the posttraining FVC was 1750 ± 380mL. The IR of the RIMT group was 66% ± 74%, which was greater than that of the control group. Still we cannot be sure if the RIMT effect was the sole cause of the discrepancy. It is possible that the control group already had better FVC in the beginning and that the improvement was less than that of the RIMT group. But the TLC and TLC predicted percentages of the RIMT group were significantly increased from the baseline after 6 weeks of RIMT compared with those of the control group. The IRs also had significant differences between both groups. These results seem to support strongly a positive effect of RIMT training.

In our study, we also found that most of the pulmonary

Table 4: Prestudy and Poststudy Chest Circumference Measurements For RIMT and Control Groups

Level of Circumference	RIMT						Control					
	Prestudy			Poststudy			Prestudy			Poststudy		
	Inspiratory	Expiratory	<i>p</i>	Inspiratory	Expiratory	<i>p</i>	Inspiratory	Expiratory	<i>p</i>	Inspiratory	Expiratory	<i>p</i>
Louis angle	79.3 ± 4.7	79.2 ± 4.7	.193	76.1 ± 6.8	75.6 ± 7.1	.048*	88.3 ± 8.3	88.2 ± 8.1	.311	88.4 ± 7.0	88.0 ± 6.3	.363
Xyphoid process	79.1 ± 4.3	78.8 ± 4.3	.096	75.7 ± 9.6	72.1 ± 9.5	.000*	84.5 ± 7.6	84.4 ± 7.4	.188	83.4 ± 8.1	82.8 ± 7.4	.220
Umbilicus	75.9 ± 7.3	75.7 ± 7.4	.168	76.4 ± 10.4	71.5 ± 10.4	.000*	85.6 ± 7.8	84.8 ± 7.6	.091	85.5 ± 7.2	82.8 ± 9.8	.217

* Significant difference ($p < .05$) of paired *t* test between prestudy and poststudy values.

function parameters, in both the training and control groups, showed significant improvement. But, for most of the variables, such as FVC, FVC (% predicted), FEV₁, PEF, PEF (% predicted), and VC, there were no significant differences between the control group and the training group.

These findings are similar to Loveridge and colleagues' study.⁹ Even allowing for the above findings, it seems that the training effects on ventilatory function and respiratory muscle strength cannot be neglected.

In addition, there were statistically significant differences between the changes in the poststudy chest circumference measurements only in the RIMT group. These findings strongly provide evidence of the effects of RIMT.

The scale measurements of resting dyspnea for both groups were improved after the study, and there were significant differences in the improvement ratios between groups. This might indicate that RIMT can improve not only the ventilation and endurance but also perceived dyspnea in complete tetraplegics.

In the study, subjects' motivation was of vital importance, as only highly motivated patients could complete the study. We had to supervise the subjects closely and encourage them to perform better. However, it is not possible to exclude the possibility of varying inspiratory flow rates, which accounted for the large variations in results in some individual subjects. Recent studies have shown that using inspiratory pressure load training can prevent these defects. The potential advantage of this kind of device is that the inspiratory pressure is independent of the inspiratory flow rate.²³⁻²⁸ Nevertheless, the relative benefits of RIMT are that it is an inexpensive training procedure that may be self-administered over the long term, and that the DHD inspiratory resistive muscle trainer is simple, light, and portable. It is readily available for the patient and suitable for home use.

CONCLUSIONS

We recommend that patients with complete motor tetraplegia be encouraged to receive RIMT soon after their medical and neurologic conditions have stabilized. This training can improve lung function, respiratory muscle strength, endurance, and perceived dyspnea.

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Suppliers

- Diemolding Healthcare Division, Canastota, NY 13032.
- SensorMedics 280D; SensorMedics Corporation, 1630 S State College Blvd, Anaheim, CA 92806.
- Micro Medical Limited, PO Box 6, Rochester, Kent, ME1 2AZ, England.
- SPSS, Inc., 444 N Michigan Ave, Chicago, IL 60611.