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Maintenance of locomotor abilities following Laufband (treadmill) therapy in para- and tetraplegic persons: follow-up studies

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Recent reports indicate that walking capabilities in spinal cord damaged persons significantly improve – as compared to conventional rehabilitation therapy – after intensive training of aided (Laufband) treadmill-stepping.[5–8] In the present report, follow up investigations on two collectives of spinal cord injured (sci) persons are described who had undergone (Laufband) treadmill therapy either during a period of renewed rehabilitation months or years after spinal cord injury (35 chronic patients) or during their first postacute rehabilitation period (41 acute patients). Among the initially chronic patients, 20 from 25 still wheelchair-bound before the onset of (Laufband) treadmill therapy, ie not capable of raising from the wheelchair and walking without help by other persons, became independent walkers after therapy. Assessment of voluntary muscle activity in resting position before and after the period of therapy had shown only small increases in most patients, indicating the involvement of motor automatisms and better utilisation of remaining muscle function during walking. Follow-up assessments performed 6 months to 6½ years after discharge from the hospital revealed that the walking capabilities achieved by (Laufband) treadmill therapy in the 35 initially chronic patients were maintained in 31 persons, in three they had further improved, in only one it was reduced. These results indicate that the improvements achieved under clinical conditions can be maintained in every day life under domestic surroundings. From 41 initially acute patients, 15 had further improved and none had reduced his walking capability 6 months to 6 years after discharge from the hospital.

Keywords: Laufband; treadmill; locomotion; paraplegic; tetraplegic; spinal cord

Introduction

In non-human primates, relearning of treadmill-stepping was described after most severe spinal cord damage, eg sparing only parts of the ventral white matter.[1] In lower vertebrates like cat, such motor learning may occur even after complete transection of the low thoracic spinal cord,[2–4] indicating the existence of spinal locomotor programs, capable, together with afferent information, of generating steplike movements in hindlimbs. In man after complete spinal transection, only elements of stepping but no full step cycles may be evoked on the treadmill.[5,6,12] Improvement of stepping in spinal cord injured cats and monkeys was achieved by intensive treadmill-stepping;[1,2] other training regimes such as daily standing were not successful and even significantly worsened stepping capabilities in cats.[15,18] Translated into strategies for motor rehabilitation of spinal cord injured patients, these observations imply that relearning of walking can be done only by intensive exercise of upright walking.

Two groups of researchers have recently, independent from each other, adopted the treadmill device for spinal cord injured persons and have reported improvement of locomotion not only on the treadmill but overground, in a considerable number of patients.[5–8] In a recent study, the applicability of treadmill therapy was investigated in 89 incompletely paralysed chronic and acute para- and tetraplegics; from the comparison with 64 patients treated conventionally and from consecutively applying both therapies in individual patients, a considerable efficacy of treadmill therapy became obvious.[6]

In the present report, results of follow-up evaluations are reported, which were performed 6 months up to 6½ years after discharge from the hospital where these patients had undergone treadmill therapy either in the course of renewed rehabilitation therapy (initially chronic patients) or in the course of postacute rehabilitation (initially acute patients). Follow-up investigations were important, since improvements in locomotion achieved by treadmill therapy had occurred under controlled clinical conditions, usually within a few weeks. Furthermore, as will be shown in detail, several patients had significantly improved their walking capabilities with little increase in voluntary muscle activity, which

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indicates the involvement of motor automatisms entrained during treadmill therapy.[6] It was particularly important to know, therefore, whether patients could maintain their new walking capabilities in domestic surroundings without daily treadmill therapy.

Follow-up investigations were performed on a total of 76 patients; pre- and post-training data from 43 of these have been reported before,[6] 14 chronic and 19 acute patients have not been previously described. Detailed information is given on all chronic patients in this study, in particular pre- and post-training assessments of voluntary muscle activities and walking capabilities.

Table 1

Wheelchair-bound:
0 = lower limbs cannot support body weight for standing or walking even with moderate help by two therapists
1 = capable of standing and walking only with the help of two therapists;
2 = walking at the railing with help of one therapist.
Not wheelchair-bound:
3 = walking with the rollator/walker or reciprocal frame;
4 = walking with two regular canes or four-point canes;
5 = walking without devices (free walking) for more than five steps.

Methods and patients

The principles of treadmill therapy have been published before.[5–8] In short, exercise of upright walking is performed on a motor driven treadmill. Patients are supported by a harness suspending from the ceiling and initially by passive movements of the limbs by therapists, if necessary. During walking 'rules of spinal locomotion' derived from animal experiments are applied to elicit locomotor automatisms whenever necessary and appropriate. Treadmill therapy was performed usually once, in some patients twice per day, for periods of 30 min on 5 days a week. As soon as possible, walking training on firm ground was carried out in parallel. Apart from this, patients participated in the regular conventional rehabilitation program for indoor patients.

Criteria for selecting patients to enter treadmill therapy: presence of some voluntary muscle activity in the lower limbs, in particular of quadriceps femoris, mobility of joints, no severe muscle shortening and no skin ulcerations or other severe disease. In the chronic patients reported here, treadmill therapy was started 6 months to 15 years after spinal cord injury (median 1½ years). In acute patients who had suffered trauma of the spinal column, the safety of the procedure had to be assured by the orthopaedic specialist; due to surgical stabilisation of the vertebral column,[11] the start of walking exercise was usually allowed within a few weeks after trauma.

The cause of spinal cord injury was most frequently trauma followed by non-progressive myelitis, tumours, vascular disorders and other causes (see Table 2). Patients with significant components of flaccid paralyses are not included in this report.

Assessments

Walking capabilities before and after treadmill therapy as well as in the follow-up investigations were classified into 6 classes (0–5) solely on the patient's ability to walk overground (Table 1). Accordingly, wheelchair-bound patients not capable of standing up and walking without help by others are separated from those not wheelchair-bound and capable of standing up from the wheelchair by themselves.

For the initial rating a distance of 5–10 meters was evaluated, but 50–100 meters for the later ratings unless stated differently. These assessments were done by two evaluators (SM and AW) independently from the video film records; in the case of discrepancies the higher class was assumed before start of therapy and the lower class later on.

The amount of voluntary muscle activity was evaluated from the force and range of movements evoked upon verbal command in defined resting positions (horizontal and sitting) avoiding readily evoked spastic extension pattern (10): 0 = no muscle contraction visible or palpable; 1 = muscle contraction visible and/or palpable, no movement of limbs; 2 = some joint angle movement with passive support by the therapist balancing gravity (tested while lying on one's side); 3 = full range of joint angle movement against gravity, 4 = full movement plus maintenance of position against moderate applied resistance; 5 = like 4, against maximal applied resistance. Values in between were allowed and valued as half points.

As overall measure for muscle function in a limb, values of the following eight major flexor and extensor muscles/muscle groups were summed: glutaeus maximus, glutaeus medius and minimus, iliopsoas, sartorius, quadriceps, ham strings, tibialis anterior and triceps surae. These values are included in Table 2.

Follow-up investigations were performed on the day patients arriving at the clinic for routine ambulatory check-ups or within the first days in the clinic in the case of renewed indoor treatment. Patients were asked to walk over ground at the optimal speed with their preferred device used at home. Video-recordings were made from all performances.

Assessment of walking capability before and after treadmill therapy from 21 of the 35 chronic patients reported here in detail are included in a previous report,[6] (patients coded 0/D–0/J, 1/A and 1/H and 2/A–2/F in Table 2). This is also the case for 22 of the 41 acute patients in Figure 2.

Table 2 Effects of treadmill therapy and carry-over effects on 25 initially wheelchair bound chronic patients

Code	*Age*	*Sex*	*Cause of damage*[a]	*Segmental level*	*Start after injury*	*Duration*	*Treadmill therapy* — *Walking capability*[b] *before/after follow up*			*Stair case walking*[c] *before/after*		*Cumulative muscle force*[d] — *right limb before/after*		*left limb before/after*	
0/A	62	f	T	Th6	10 months	20 weeks	0	4	5	no	yes	13	26	19.5	30
0/B	25	m	T	C5*	8½ months	18 weeks	0	3	3	no	yes, s.p.	4.5	10.5	5	8.5
0/C	25	m	T	Th7	6 years	12 weeks	0	3	3	no	yes, s.p.	3	4	2.5	3.5
0/D	67	m	T	C6*	5½ months	18 weeks	0	3	3	no	no	1	4	5	18.5
0/E	22	f	M	C5*	12 months	16 weeks	0	3	3	no	no	24	29.5	0	0
0/F	50	f	T	C5*	12 months	11 weeks	0	3	5	no	yes, s.p.	15	23.5	18.5	26.5
0/G	21	m	T	C7*	22 months	10 weeks	0	2	2	no	no	8.5	12.5	5	7
0/H	52	m	Tu	Th12	20 months	9 weeks	0	2	2	no	no	14	17	16	17.5
0/I	49	m	T	C5*	6 months	20 weeks	0	2	3	no	no	7	10	5.5	7.5
0/J	30	m	T	C5**	6 months	20 weeks	0	1	1	no	yes, s.p.	8	13.5	10	15
1/A	19	f	T	Th10	11 months	12 weeks	1	4	4	no	yes	4	5.5	15	15.5
1/B	56	f	V	Th6	2 years	18 weeks	1	4	4	no	yes	8.5	10.5	24	25.5
1/C	56	m	T	C5*	4 years	11 weeks	1	3	3	no	yes, s.p.	13.5	14	12.5	13
1/D	35	m	T	Th7	15 months	8 weeks	1	3	3	no	no	5.5	7	11.5	14.5
1/E	56	m	V	Th3	12 months	14 weeks	1	3	3	no	no	13.5	16.5	13	17.5
1/F	51	m	T	C4*	4 years	13 weeks	1	3	2	no	no	7.5	8	11.5	15
1/G	24	m	T	C5*	12 months	10 weeks	1	3	3	no	no	15	20.5	8.5	9
1/H	50	m	T	C6**	15 years	8 weeks	1	2	2	no	no	11	11	4.5	5.5
2/A	70	f	Tu	C8	3 years	9 weeks	2	5	5	no	yes	19	21.5	20	22.5
2/B	50	m	T	C5	5½ months	18 weeks	2	5	5	no	yes	8	17.5	7.5	16
2/C	29	f	T	Th10	10 months	8 weeks	2	5	5	no	yes	24	27.5	5	10
2/D	55	m	M	C6	11 months	10 weeks	2	4	4	no	yes	12.5	23.5	13.5	24
2/E	28	f	T	C7*	12 months	16 weeks	2	4	4	no	yes	27.5	31	7	14.5
2/F	30	m	T	C4*	13 months	14 weeks	2	4	4	no	yes, s.p.	6	10	29	30
2/G	49	m	T	C5*	12 months	10 weeks	2	3	3	no	yes, s.p.	6.5	6.5	8	12.5

[a]M = myelitis, T = trauma, Tu = tumour, V = vascular disorder. [b]Walking capability: 6 main classes defined in the text (see Table 1) [c]Stair case walking: with railing and one cane or one supporting person (s.p.). [d]Cumulative force of 8 major flexors and extensors determined in resting position (see Methods). s.p.: Supporting person needed. *Severe arm paralysis. **Incapable of using devices due to arm paralysis

Results

Initially chronic patients

Walking capabilities pre and post-treadmill therapy of 35 para- and tetraplegic patients with spastic paresis are summarized in Figure 1 (upper and middle histograms). Out of 25 wheelchair-bound patients (classes 0–2, black bars in the upper histogram in Figure 1) only five remained so and 20 became independent after treadmill therapy. Patients already independent before treadmill therapy (classes 3–5, open bars in the upper histogram in Figure 1) usually remained within their original functional class (only two patients advanced to higher classes), but all improved in speed and endurance of walking (data not shown). Median duration of treadmill therapy was 12 weeks (range 8–20 weeks) for wheelchair-bound patients (Table 2) and 10 weeks (range 4–12 weeks) for the others. Antispastic medication, applied in 27 of the 35 patients, was maintained in eight but could be reduced in the course of treadmill therapy in 19.

Marked increases in voluntary muscle activity in the course of treadmill therapy surprisingly had occurred only in few patients (marked 0/A, 0/D left limb, 0/F, 2/B and 2/D in Table 2); noteworthy, four of these five patients were among those in which Baclofen medication was markedly reduced. Strikingly on the other hand, limbs often remained near completely paralysed, ie had cumulated values of 10 and lower for the eight major flexor and extensor muscles in this limb (see Methods), with no single muscle exceeding 2½ (patients coded 0/C, 0/D, 0/E, 0/G, 0/I, 1/A, 1/F, 1/G, 1/H and 2/G in Table 2).

The follow-up investigations performed 6 months to 6½ years later (median 20 months) show that the improvements achieved under clinical conditions by treadmill therapy were generally maintained (Figure 1, lower histogram and Table 2). Only one patient fell back from class 3 to 2 while one patient improved from 2 to 3 and two patients improved from 3 and 4 to 5.

Initially acute patients

41 para- and tetraplegic patients had started treadmill therapy 3–16 weeks (median 8) after spinal cord damage and performed it as part of their postacute rehabilitation for periods of 3 to 22 weeks (median 10). Figure 2 (upper and middle histograms) compares their walking capability at the beginning and end of treadmill therapy; according to this, eight patients were still wheelchair-bound (classes 0–2) after the end of their first rehabilitation. At the follow-up investigation 6 months to 6 years after discharge from the clinic, median 17 months), only six patients had remained wheelchair-bound, fewer patients needed a walker (class 3), clearly more patients could walk for short distances also without any devices (class 5) (lower histogram). In summary, 15 of the initially acute patients further improved and none of them reduced his walking capability after discharge from the clinic.

Discussion

It has previously been reported[5–8] that spinal cord injured patients may improve their walking capability significantly by intensive training of upright walking on

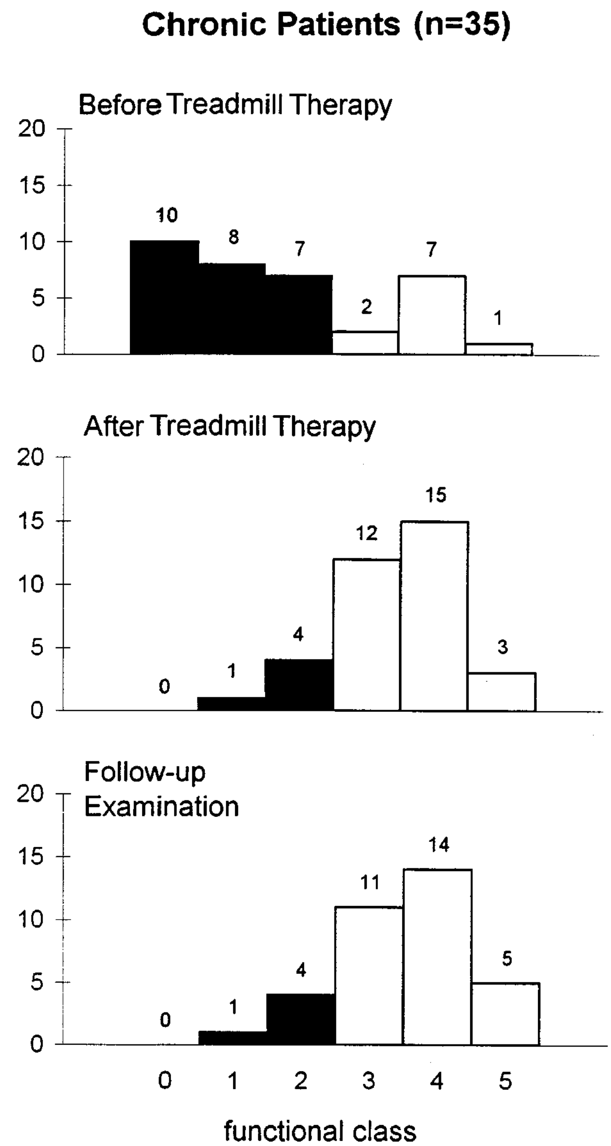

Figure 1 Walking capabilities according to 6 functional classes (0–5) in 35 chronic para- and tetraplegic patients before (upper histogram) and after treadmill therapy performed in the clinic (middle histogram) as well as 6 months to 6½ years (median: 20 months) after discharge from the hospital (lower histogram, follow-up investigation). Functional classes 0–2 (black bars): patients wheelchair-bound. Functional classes 3–5 (white bars): patients not wheelchair-bound, see Table 1. Numbers on the columns give number of patients in this class

a treadmill. The present report adds another 33 patients to this account. In addition, the detailed account of voluntary muscle activity with evolving improvement in walking reveals a striking dissociation: while some increase in voluntary muscle activity occurred in all patients, large increases were strikingly rare and confined to five from 25 initially wheelchair-bound chronic patients; in four of these antispastic medication – known to inhibit voluntary activity – had been reduced. One is bound to conclude, therefore, that most of the improvement in locomotor activity was due to better utilization of the remaining voluntary motor activity and the involvement of motor automatisms. This phenomenon was most striking in the patient coded 0/C, who learned to walk for distances of 20 – 40 meters with the help of a rollator, though his voluntary activity in the lower limbs did not exceed 3.5 and 4 (Table 2). An even more striking discrepancy, assessed functionally and electromyographically, was observed in a patient with zero voluntary activity in one limb and a total value of 2 in the other[5] (patient Z). Motor automatisms seem to be evoked when applying 'rules of spinal locomotion' (see Wernig and Müller,[5] Wernig *et al*[6] and Grillner[13] for reviews) and might thus be of spinal origin, though in primates supraspinal influences might be involved as well. One of these features, limb loading during stance, has recently been shown to dramatically enhance motor output from muscles of this limb in persons with complete (and incomplete) spinal cord transections, supporting the idea that the isolated spinal cord correctly interpretes proprioceptive afferent information in the sense of maintaining upright body position.[9,14] Applying these rules, elements of stepping on the treadmill short of complete step cycles, could recently be evoked in a 13-year old girl completely paralysed below spinal segment Th 6[12] (detailed manuscript in preparation; see also Wernig and Müller[5] and Wernig *et al*[6] for further reports on elements of stepping after complete spinal cord transection, and Dobkin *et al*[16] and Dietz *et al*[17] for phasic and alternating flexor and extensor muscle activity during aided stepping).

In the light of the present findings, strategies of rehabilitation for incomplete para- and tetraplegic persons need to include intensive training of upright walking emphazising the 'rules of spinal locomotion'. This of course can also, though involving considerably more effort, be achieved by other means than training on a treadmill with body weight supported by a harness. However, there are obvious obstacles involved in some other strategies which need to be noticed: Walking in water, most helpful initially with severe paralyses, precludes proper limb loading. When already capable of some walking, patients training in parallel bars or with canes or a rollator often have the tendency to maintain upright body position by body weight support via arms and the mechanical devices, such that limb loading might not occur to a sufficient degree. Limb loading might also be insufficient during motor-supported bicycling. Results of the follow-up investigations on chronic and acute patients indicate that walking capability generally can be maintained at home. Since not all patients from our original study[6] could be investigated now, the precise amount of maintenance of relearned locomotion is not known. Still, the present results support the notion that upright walking – once it is achieved – is the best training to maintain and improve walking capability

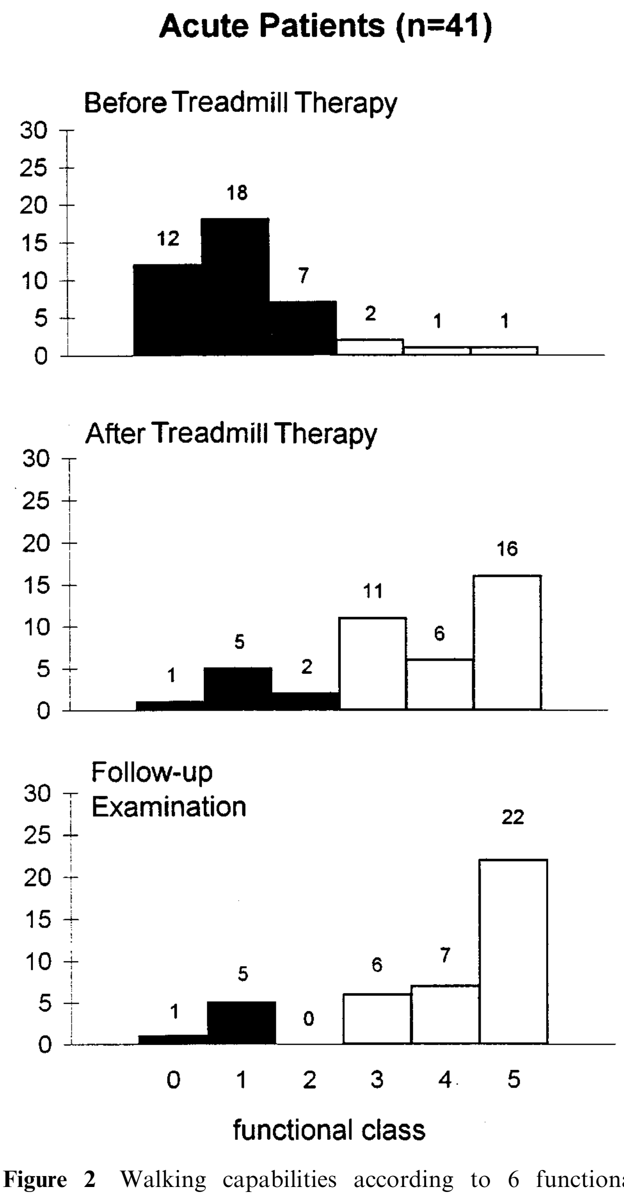

Figure 2 Walking capabilities according to 6 functional classes (0 – 5) in 41 acute para- and tetraplegic patients with spastic paralyses. Upper histogram: before treadmill therapy, 3 to 16 weeks (median 8 weeks) after spinal cord damage. Middle histogram: the same patients at discharge from the clinic. Lower histogram: follow-up investigations 6 months to 6 years (median 1½ years) after discharge from the clinic. Numbers on the columns indicated number of patients in this class

even in patients with little voluntary muscle activity. However, for many patients, especially the most handicapped ones including those with arm, shoulder and rump paralyses, the amount of walking mastered during a day is bound to be lower than performed even in a single session of 30 min on the treadmill (about 0.3 to 1.5 km). Obviously, such patients might further improve their motor capabilities by continuing training on the treadmill after discharge from hospital.

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