COMPUTER-ASSISTED GAIT TRAINING(CAGT) FOR HEMIPARETIC STROKE PATIENTS

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NATIONAL REHABILITATION CENTER
FOR THE DISABLED
JAPAN

(WHO COLLABORATING CENTRE)

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National Rehabilitation Center for the Disabled
WHO Collaborating Centre for Disability Prevention & Rehabilitation

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Computer-Assisted Gait Training (CAGT) for Hemiparetic Stroke Patients

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PREFACE

According to the World Health Report 1997 (WHO), more than 4.6 million deaths world wide are due to cerebrovascular diseases, one-third in industrialized countries and the rest in developing countries. About one-third of stroke patients die within six months since stroke onset, and survivors may be severely disabled, with hemiparesis, loss of speech and/or others. National survey on physically disabled persons performed in 1996 by Ministry of Welfare indicates that the most common cause of physical disabilities is cerebrovascular accidents in Japan. Several clinical studies have shown that most of functional recovery, including walking capacity, occurs within 6 months after stroke onset, except language function. Those epidemiological and clinical data suggest the utmost importance of both the primary prevention of cerebrovascular diseases and second-level prevention of physical disabilities in post-acute phase of stroke.

We have promoted research works related to Recovery Evaluating System (RES) for Stroke Rehabilitation, and using RES, we have attempted to evaluate various approaches of the physical therapy for post-stroke patients. In this manual we describe the detail of computer-assisted gait training (CAGT) program, which was developed in Institute of Rehabilitation Medicine and Narugo-Branch Hospital, Tohoku University School of Medicine, Miyagi, Japan. CAGT has been used clinically for more than 12 years. At present, CAGT is routinely ulitized in physical therapy of stroke inpatients in National Rehabilitation Center for the Disabled, Hospital ; Tohoku University School of Medicine, Hospital ; and other hospitals.

We hope that physicians, physical therapists, and staffs of other health care professions participating for post-acute stroke rehabilitation will utilize this manual to promote the recovery of walking capacity.

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List of abbreviations

A-IK : Maximum isokinetic knee extension (from 90 to 0 degrees with an angular velocity of 30°/sec) torque of the affected side (Nm)
CAGT : Computer-assisted gait training
CFP : Center of feet pressure
FB% : The change in CFP while shifting the body weight forth-and-back (ratio to the length of base of support)
IV : MWS at the start of CAGT (initial value)
LR% : The change in CFP while shifting the body weight left to right (ratio to the length of base of support)
MWS : Maximum walking speed (m/min)
N-IK : Maximum isokinetic knee extension (from 90 to 0 degrees with an angular velocity of 30°/sec) torque of the non-affected side (Nm)
SL : Stride length (m)
SP : Sway path (cm/10 sec)
TSO : Time since stroke onset (weeks)
WR : Cadence (walking rate : steps/min)

INTRODUCTION

The major goals of medical rehabilitation for survivors of acute stroke include the recovery of lost function, for instance, walking capacity and independence in self-care. Several studies have shown that most of functional recovery, including gait, occurs within the first 3 months and improvement thereafter, although observed, does not reach the level of statistical significance except for the language function (Andrews et al. 1981, Skilbeck et al. 1983, Kelly-Hayes 1990). Similarly the increase of maximum walking speed for the 10 m distance is prominent only during the first 4 weeks after the start of gait training (Nakamura et al. 1998 a). Skilbeck et al. (1983) reported that rapid early improvement of walking capacity was seen following a stroke but that little changes occurred after 6 months. Wade et al. (1987), examining the pattern of recovery of walking capacity over the first 13 weeks post-stroke, reported that the longer a patient took to start gait training the less likely he was to regain normal speed within 13 weeks. Accordingly, it is important to facilitate functional gain in walking capacity during the early phase of physical rehabilitation. For that purpose we developed a computer-assisted gait training (CAGT) program, which made it possible to analyze and predict walking capacity and to increase the functional gain during intensive physical therapy (Nakamura et al. 1988 b, 1988 d). We have utilized the CAGT program for more than 10 years. The results are encouraging. In this manual we describe the details of the CAGT program and related research works.

1 COMPUTER-ASSISTED GAIT TRAINING (CAGT) PROGRAM FOR HEMIPARETIC STROKE PATIENTS

The CAGT program is a kind of programmed learning specially designed for post-stroke hemiparetic patients (Nakamura et al. 1988 d), and is based on the following premises : (1) recovery from physical disability after a stroke follows a predictable pattern and it is possible to develop profiles with which an individual's progress could be compared (Partridge et al. 1987) ; and (2) recovery of walking capacity, i. e., the improvement of maximum walking speed relative to the cadence and stride length of stroke patients, also follows a predictable pattern (Nakamura et al. 1988 c).

[1] The Abridged Version of CAGT Program

1) Measurements of patient's gait components

The time and the number of steps necessary to walk a 10 m distance on flat floor bounded by two tapes are measured using a digital stop watch (Nakamura et al. 1985) prior to the start of the CAGT and usually once a week thereafter. Gait is tested by asking the patient to walk 10 m as fast as possible on a level walk-way bounded by reflectorized tapes. The examiner, usually the physical therapist in-charge, takes an accurate measurement of each gait trial while following closely behind the patient. The patient begins each trial at least a few strides short of the starting line and the timing commences as soon as the patient's swing leg crosses over the starting line and ends when the patient's swing leg passes over the finish line. The patient performs three to five trials in each session, and the fastest trial is chosen as data. The data, the measured time and the number of steps, are fed into a personal computer*, which is programmed to calculate the following : (1) the walking speed (m/min), (2) the cadence (steps/min), and the average stride length (m). The computer plots the results of the gait performance superimposing line graphs of standard values based on 208 data, which were gathered from 58 post-stroke hemiparetic patients previously admitted at the Narugo-Branch Hospital, Tohoku University School of Medicine. Figure 1 shows an example of the computer display.

2) Instruction to the patient

The physical therapist shows and explains the results of the gait performance to the patient. Comparing the patient's data with the standard values, the patient is then instructed which particular gait variable needs to be improved by subsequent training, i. e., either cadence or stride length. In Figure 1 the patient has performed his gait trial with a walking speed of 16.3 m/min, cadence of 96.2 steps/min and mean stride length of 0.34 m. Since the stride length is insufficient as compared with the standard, the aim of training is to increase the stride length without decreasing the cadence, which would result in the increase of walking speed.

4) Prediction of functional outcome

When the data of more than 2 weeks after starting CAGT, i. e., more than 3 sessions, are gathered, the prediction of functional outcome becomes possible. Applying a hyperbolic function, $y=A-B/x$, in which x is the time since stroke onset (weeks) and y is the maximum walking speed (m/min),

* Computer software for RES-4 (Windows 95®) including the CAGT program is now available from Sakai Iryo Co, Tokyo, Japan (Nakamura 1995).

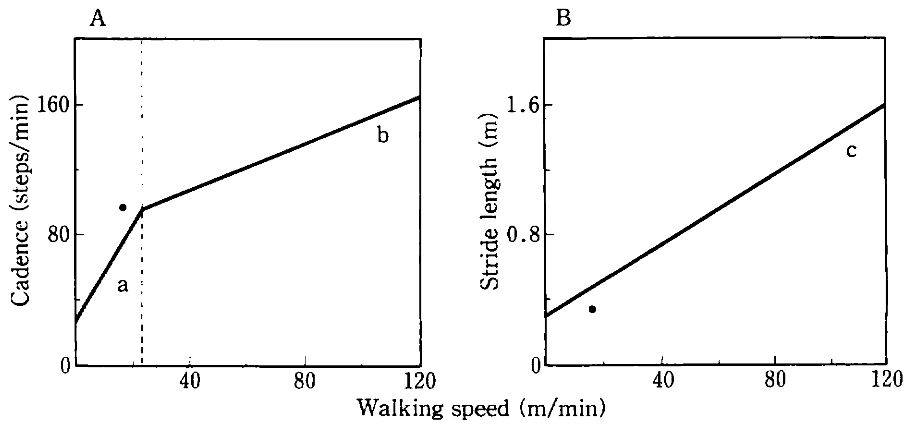

Figure 1 An example of the computer display

A : relation of maximum walking speed to cadence.

B : relation of maximum walking speed to stride length.

Lines of linear regression were calculated with 208 gait trials of 58 stroke patients.

a : $y=29.5x+26.7$ ($R^2=0.75$)

b : $y=0.73x+78.1$ ($R^2=0.67$)

c : $y=0.0109x+0.296$ ($R^2=0.90$)

The dot in A and B is the results of gait trial of a patient.

(Nakmura et al. 1988 d)

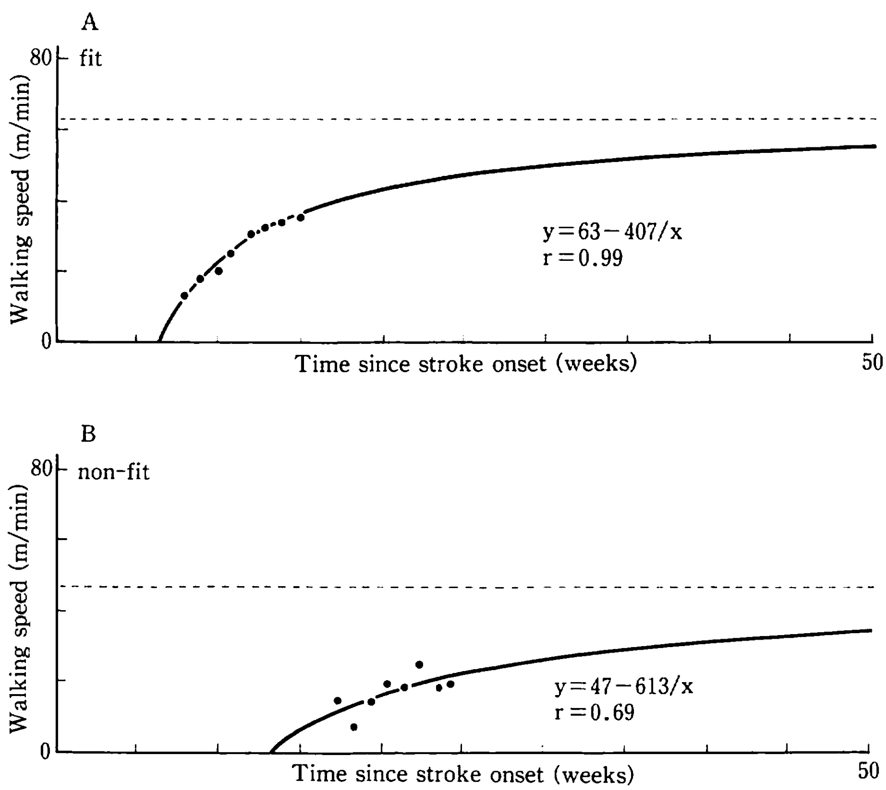

Figure 2 The relation between the time since stroke onset and the maximum walking speed of two cases

A : left hemiparesis, 66 years old female, belonging to the fit group.

B : left hemiparesis, 50 years old female, belonging to the non-fit group.

(Nakamura et al. 1992)

values of parameters A and B are estimated by a least square approximation. Figure 2 demonstrates two illustrative cases, in which the relationship between the time since stroke onset and the maximum walking speed is statistically significant in case A but not in case B.

[2] Practice of Physical Therapy

Techniques of physical therapy for stroke patients based on the developmental approach were already reported in detail (Nakamura 1977). The following are special considerations related to the CAGT program not mentioned previously.

1) Stability of standing balance

Inability to stand on both feet in hemiparetic patients is related to the impaired antigravity function of the affected side and/or the decreased function of static standing balance. Before starting CAGT, improvement of standing balance is indispensable.

(1) For the muscle weakness of the affected side a plastic ankle-foot-orthosis (AFO) is usually prescribed, which reduces mediolateral instability of the ankle joint and decreases postural sway during standing (Mojica et al. 1988). In some cases, knee-ankle-foot orthosis (KAFO) or knee orthosis (KO) is necessary to compensate for the instability of joints.

(2) An initial procedure to stabilize standing posture is to increase the base of support. At first, a wide-based standing posture is recommended, and standing exercise using the parallel bars, T-cane or quadricane is preferable.

2) Cadence

The increase of cadence is related to voluntary effort of the patient. Additional considerations are as follows :

(1) The physical therapist encourages the patient to initiate the next step as fast as possible.

(2) In patients with the foot in functional equinovarus due to spasticity, and unable to keep the foot-flat position during mid-stance on the paretic side, active-assistive dorsal-flexion exercises of the ankle joint should be practiced in both the supine and the standing positions followed by the active exercises under supervision.

(3) In patients with the hyperextended knee and the flexed hip joint, forward movements of the pelvis are limited, i. e. the retracted hemipelvis, and weight bearing on the affected side is incomplete. Weight bearing on the affected lower extremity is practiced as active-assistive exercises with movements in the lateral, the fore-aft and/or the diagnonal directions. At first, the physical therapist should handle the patient's pelvic girdle, and later the shoulder girdle. The patient is recommended to try the same movements as active exercises, using the parallel bars or stall bars.

(4) In patients showing hyperextension of the knee or backward thrust of the affected lower extremity during midstance, active assistive knee flexion and ankle dorsiflexion exercises should be practiced while maintaining the standing position and weight-bearing on the affected side.

3) Stride length

The increase of stride length during gait training is mainly dependent upon the patient's effort. The following exercises are recommended : In patients with a maximum walking speed greater than 40 m/min, the asymmetry of posture and gait components such as step length should be carefully corrected, using verbal commands and passive movements.

(1) The patient is frequently asked to walk with a long step.

(2) When the patient can not make a long step on the non-affected side. the physical therapist puts some markers 10-30 cm in front of the patient. A relatively flat platform or stairstep could be used as a marker. helping to improve the antigravity function of the affected side.

(3) In patients with a flexed hip on the affected side at terminal stance. passive and active stretching of the hip joint on the affected side should be performed in both lying and standing positions.

(4) In patients with retracted hemipelvis on the non-affected side. active-assistive trunkal rotation exercises should be practiced on lying and standing position in order to reduce the stiffness of truncal muscles.

(5) If the patient complains of fatigue and/or the walking speed becomes slow. a rest should be taken for a few minutes. The number of gait trials should be increased gradually. It is recommended that the walking distance should be increased daily. The patient should practice frequently for short period of time. rather than spending long period of time doing gait trials over and over.

2 APPENDIX

The following are summaries of original reports published previously.

[1] Walking Cycle after Stroke (Nakamura et al. 1988 c)

Several studies on quantitative gait analysis of hemiparetic stroke patients have indicated that temporal-distance parameters are clinically useful indicators for assessing gait performance and monitoring recovery (Mizrahi et al. 1982, Brandstater et al. 1983). Since walking speed improves during the first 12 weeks and there is little consistent improvement after 3 months (Wade et al. 1987), it is important to analyze the changes that are taking place in the gait components during the period of greatest recovery. We recorded the changes in the gait components within an 8-week period after starting a conventional gait training in stroke patients.

Ten hemiparetic patients aged 44 to 70 years old participated in the study. The duration from the stroke onset to the start of gait training was 2.1 (range : 1.2-4.5) months. The patients walked as fast as possible on a specially manufactured 10 m walkway which automatically calculated the average speed (m/min), cadence (steps/min) and stride length (m). The measurements were performed prior to the start (0 week), in the middle (4 weeks), and at the end (8 weeks) of a conventional physical therapy program with gait training.

Table 1 presents means and S. D. s of the gait components, i. e., walking speed, cadence and stride length. There was a significant difference in each variable between the three measurements ($p<0.01$). Walking speed significantly correlated with cadence and stride length in each measurement ($p<0.05$). Both at 0 and 8 weeks, a significant correlation was observed consistently between each variable and the time since onset, except for the stride length at 0 week. At 4 weeks, walking speed and stride length were primarily related to the stage of motor recovery (Brunnstrom 1970), and cadence to the duration of illness. These results confirm previous reports that improvement of gait performance takes place rapidly during the early recovery phase (Wade et al. 1987) and is coupled with recovery of muscle strength of the paretic lower extremity (Nakamura et al. 1985, Bohannon 1986). Moreover, the longer a patient takes to start gait training, the lesser the chance that he/she

Table 1 Means of maximum walking speed, cadence and stride length prior to the start (0), in the middle (4) and at the end (8) of 8 weeks gait training.

	Duration of training (weeks)		
	0	4	8
Maximum walking speed (m/min)	15.3 (6.6)	25.2 (9.7)	34.7 (12.3)
Cadence (steps/min)	68.1 (18.0)	88.8 (19.7)	106.2 (20.4)
Stride length (m)	0.44 (0.10)	0.55 (0.15)	0.64 (0.16)

( ) : S. D. (Nakamura et al. 1988 c)

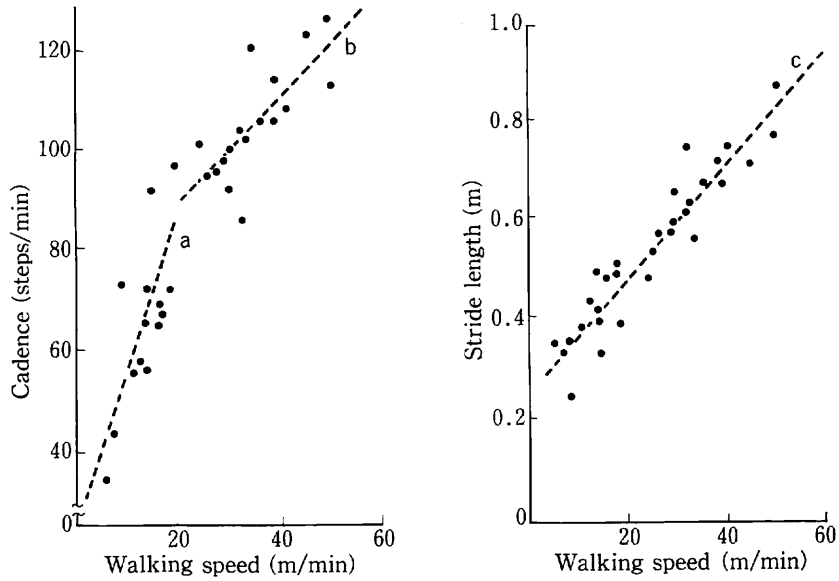

Figure 3 Relationship of maximum walking speed to cadence and stride length

Dashed lines (a, b, c) of linear regression are ;
a : WR=3.25 MWS+23.0, r=0.746, p<0.01 ;
b : WR=1.13 MWS+66.4, r=0.755, p<0.01 ; and
c : SL=0.012 MWS+0.25, r=0.940, p<0.01.
MWS : maximum walking speed, WR : cadence, and SL : stride length.

(Nakamura et al. 1988 c)

would regain good performance. Figure 3 shows the relationship of walking speed to cadence and stride length. The slope of the regression equation between walking speed and cadence is rather steep, when walking speed is slower than 20 m/min and cadence is fewer than 90 steps/min. The relationship of walking speed to stride length is consistent. In the group with walking speed slower than 20 m/min, the correlation between the increase in walking speed and the increases in cadence and stride length were all significant ($p<0.01$). However, the correlation between cadence and stride length was not significant. Both cadence and stride length appeared to be variables that determined independently the walking speed in those patients. In the group with walking speed faster than 20 m/min, the correlation was significant only between the increase of walking speed and that of stride length ($p<0.01$). In hemiparetic patients with walking speed faster than 20 m/min, a limiting factor of walking speed was the decreased stride length. It seems that the relationship of walking speed to cadence and stride length indicates a typical recovery process of walking capacity in stroke patients.

[2] The Recovery Process of Maximum Walking Speed after a Stroke Fits the Hyperbolic Function by CAGT (Nakamura et al. 1988 d)

The maximum walking speed of hemiparetic stroke patients under the CAGT program was compared with that of patients being prescribed the conventional gait training program.

Thirty hemiparetic stroke patients aged 44 to 80 years old participated in the study. The time since stroke onset was 4 to 20 weeks before the start of gait training. Seventeen patients underwent a conventional gait training program for at least 5 weeks (range : 5-14 weeks) and served as the control group. The remaining 13 patients were managed using CAGT program for more than 4 weeks

Table 2 Characteristics of the control and experimental groups

	Control	Experimental
Sex (male : female)	4 : 13	11 : 2
Side of paresis (left : right)	11 : 6	6 : 7
Age (years)	59.9	57.2
	(8.2)	(7.8)
Stage of motor recovery	4.1	3.5
	(1.5)	(1.5)
Time since onset (weeks)	10.8	11.0
	(4.5)	(4.7)

( ) : S. D. (Nakamura et al. 1988 d)

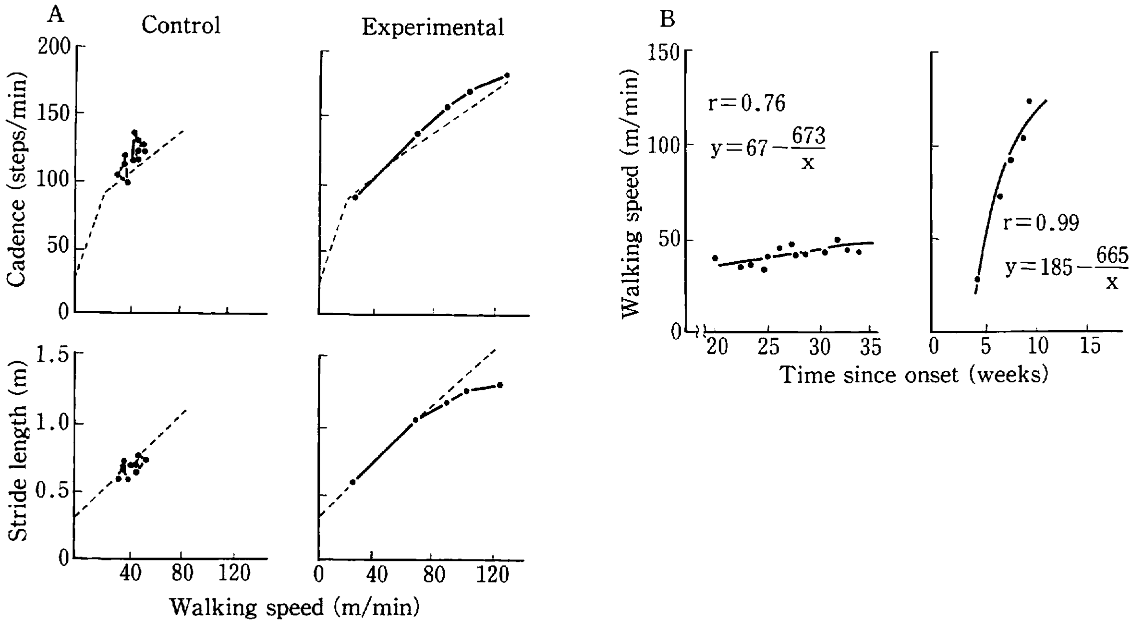

Figure 4 Sequential changes of the cadence and the stride length relative to the maximum walking speed (A) and those of the maximum walking speed to the time since stroke onset (B) in two patients

The time since stroke onset is 20 weeks for control, N. T., left hemiplegia, female and 45 years old, and 5 weeks for experimental, K. K., left hemiplegia, female and 48 years old. The figures clearly demonstrate that the earlier the gait training starts, the more the functional gain in a short period.

(Nakamura et al. 1988 d)

(range : 4-10 weeks). Both groups were also prescribed physical therapy using the developmental approach (Nakamura 1977). Table 2 presents characteristics of the control and the experimental groups at the start of gait training. Gait measurements were performed prior to the start of gait training and once a week thereafter for at least 4 weeks. Successive changes in gait components, i. e., walking speed, cadence and stride length, were recorded.

The characteristics of both groups were not different significantly except for the sex-difference. Since sex-difference of stroke patients is not related to impaired gait performance (Holden et al. 1986, Bohannon 1987), the difference of variables in gait components between the two groups could be due to the difference of gait training programs. Figure 4 presents an example of sequential changes of cadence and stride length relative to walking speed, and that of walking speed to the time since stroke onset in two patients, N. T. and K. K., belonging to the control and the experimental group, respectively. Although the relationship of cadence and stride length to walking speed follow the standard values in N. T and K. K, those of K. K. approximate the standard values more than those of N. T. The relationship between time since onset of stroke (x) and walking speed (y) can be presented in terms of a coefficient for the hyperbolic function, $y=A-B/x$. Compared to N. T., a high correlation coefficient was obtained in K. K. Applying the formulae to each patient, we obtained the

Table 3 The parameters (A and B) and the correlation coefficient (r) of hyperbolic function, $y=A-B/x$, of each patient in the control and experimental groups

Control					
Patient	N	A	B	r	*p*
S. H.	10	112	354	0.98	**
Ki. K.	7	47	431	0.98	**
K. S.	6	81	351	0.98	**
Y. A.	8	89	610	0.96	**
I. G.	7	154	2211	0.92	**
M. Y.	7	132	450	0.89	**
C. H.	8	44	249	0.84	**
S. T.	5	127	355	0.82	—
T. O.	5	96	404	0.76	—
N. T.	11	67	673	0.76	**
Ki. S.	6	61	304	0.74	—
M. M.	9	135	310	0.62	—
M. A.	8	97	194	0.39	—
M. I.	8	21	129	0.31	—
K. A.	14	65	144	0.23	—
T. T.	10	96	45	0.13	—
T. S.	8	80	20	0.12	—

Experimental					
Patient	N	A	B	r	*p*
Y. O.	10	49	489	0.99	**
K. K.	5	185	655	0.99	**
T. I.	9	71	1216	0.98	**
M. S.	4	218	810	0.97	*
K. I.	4	208	2058	0.97	*
Te. T.	5	158	830	0.96	**
Te. S.	9	109	994	0.96	**
Ka. K.	9	177	994	0.93	**
Y. I.	9	75	732	0.91	**
Ma. S.	10	60	422	0.90	**
A. S.	7	155	2787	0.89	**
Ka. I.	9	119	1344	0.84	**
N. S.	6	111	382	0.80	—

y : maximum walking speed, x : time since onset
N : number of gait measurement.
$^{*}p<0.05$, $^{**}p<0.01$.

(Nakamura et al. 1988 d)

values of parameter A and B, and the correlation coefficient (Table 3). The ratio of patients with significant correlation between x and y to those without was definitely larger in the experimental than in the control group ($p<0.05$). This indicated a high feasibility of CAGT program for predicting the recovery of walking capacity in the experimental group. Moreover, the 'A' value of the patients with significant correlation tended to be larger in the experimental group compared to the control group, suggesting that the maximum walking speed that could be attained is high in the experimental group. The CAGT program, utilizing patient's cognitive function, facilitates the natural recovery of walking capacity and enhances the functional gain. Also, CAGT makes it possible to predict the walking capacity, i. e., the maximum walking speed.

[3] How to Approximate the Relationship Between the Time Since Stroke Onset and the Maximum Walking Speed to Hyperbolic Function, $y=A-B/x$

(Nakamura et al. 1991)

Although the approximation of the relationship between the time since stroke onset (TSO) and the maximum walking speed (MWS) by the hyperbolic function is possible with data from two measurements of different weeks, data from more than four measurements are preferable to obtain an equation which is relatively accurate for the prediction of MWS. Practically, five data could be obtained within 4 weeks in the CAGT program, which are sufficient for the prediction of outcome. The approximation to the hyperbolic function, $y=A-B/x$, is performed by means of a linear regression between the reciprocal number of TSO and MWS (Figure 5). In the equation, y is MWS (m/min) and x is TSO (weeks). In this way the parameters A and B are determined.

There are a few patients walking with slow speed at the start of CAGT due to disuse syndrome

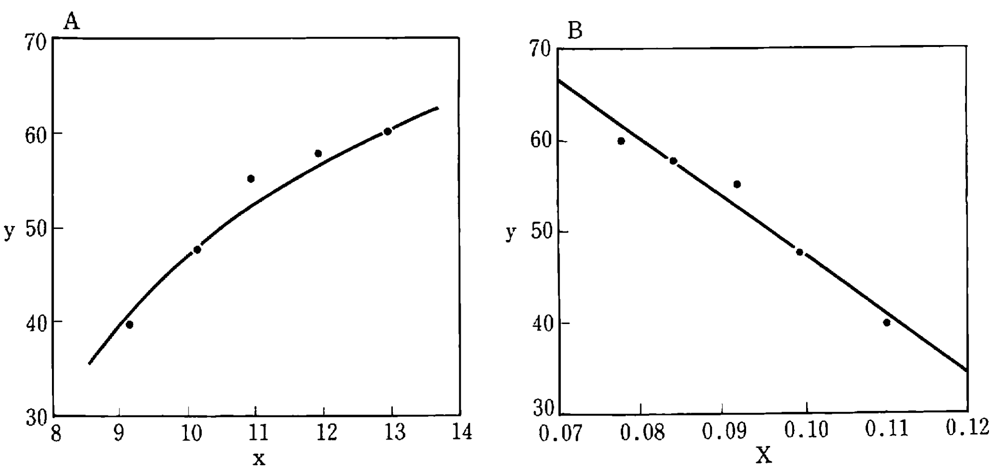

Figure 5 Approximation by a hyperbolic (A) and a linear function (B)

x : the time since stroke onset

y : the maximum walking speed.

X : 1/x

Data of 5 points correspond to (x, y) = (9.1, 39.7), (10.1, 47.6), (10.9, 55.1), (11.9, 57.7), (12.9, 60.0)

A : $y=111.5-643.8/x$

B : $y=111.5-643.8X$

$R^2=0.96$

(Nakamura et al. 1991)

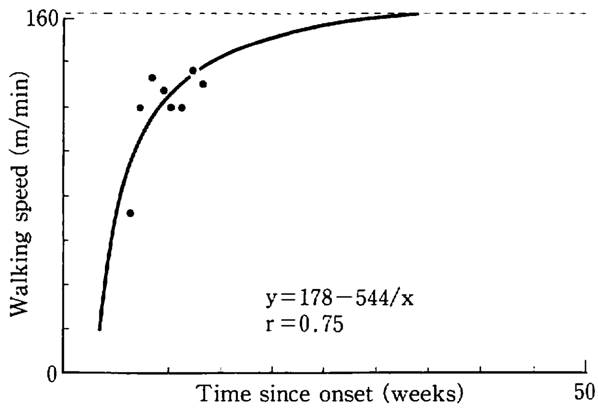

Figure 6 Relation of the time since stroke onset to the maximum walking speed in a patient with disuse syndrome

(Nakamura et al. 1991)

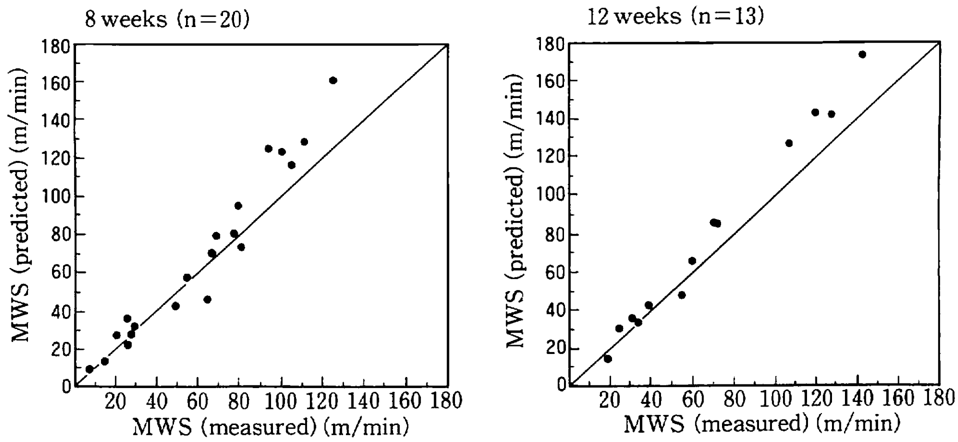

Figure 7 Relation between the measured maximum walking speed and the predicted one

Using the data within 4 weeks after starting CAGT, the approximation to hyperbolic function was performed, and the predicted maximum walking speed at 8 and 12 weeks later was calculated.

(Nakamura et al. 1991)

caused by staying in bed all day long, although their neurological impairments are mild or moderate. Those patients show rapid increase of MWS within 1-2 weeks after starting CAGT. Thereafter, the improvement of MWS is minimal (Figure 6). In some of those patients, the approximation does not reach a statistical significance.

Figure 7 presents the relationship between the measured MWS and the predicted one from the equation which was calculated using 4 weeks' data at 8 and 12 weeks after starting CAGT. In patients with MWS above 100 m/min at 8 or 12 weeks after starting CAGT, the differences between measured and predicted values are rather large. In fact the differences at 12 weeks tend to be statistically significant. However, the differences are negligible in those with MWS below 100 m/min (Table 4). Our previous study proved that stroke patients with MWS more than 80 m/min were independent in most activities of daily life, including care of elderly parents or sick family members (Sajiki et al. 1989). Accordingly, it is recommended that the prediction should be used only for speeds below 100 m/min within the set time of 12 weeks after starting CAGT.

Table 4 Ratio between the estimated and the measured maximum walking speed at 8 and 12 weeks after starting CAGT

measured speed/predicted speed×100 %	
8 weeks	n=20 94.1 (17.4)%
12 weeks	n=13 92.5 (14.4)%

patients with MWS below 100 m/min	
8 weeks	n=15 97.9 (18.3)%
12 weeks	n=9 95.7 (16.4)%

mean (S. D.) (Nakamura et al. 1991)

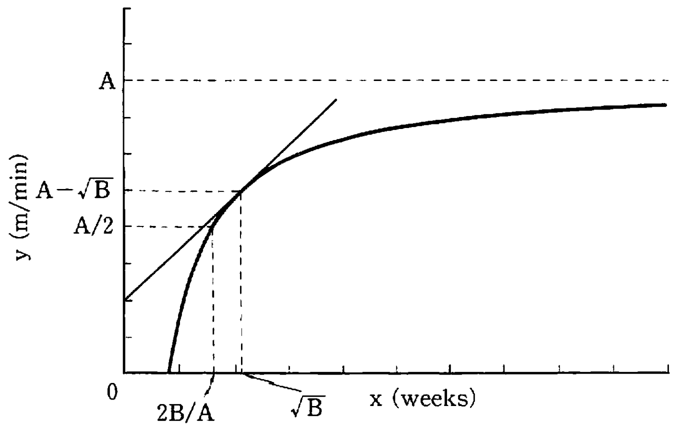

Figure 8 Variables predicted by the use of hyperbolic function
See text.
(Nakamura et al. 1991)

When the hyperbolic function obtained by the approximation is statistically significant, we can estimate the following, using parameter A and B. In Figure 8 we substitute 80 for A and 321 for B.

A is the asymptotic value, presenting the attainable MWS in the future.

A/2 is a half of the attainable MWS, and 2 B/A is the time (TSO : weeks) when MWS becomes A/2. $A-\sqrt{B}$ and $\sqrt{B}$ indicate the point at which the tangent line, $y=x+C$, comes into contact with the hyperbolic curve, $y=A-B/x$. Around this point, the gain of walking speed would be 1 m/week. Before that point, the gain of walking speed could be more than 1 m/week, and after that point, less than 1 m/week.

Based on the data of 65 patients with statistically significant approximation, determinants of parameters A and B were analyzed using age, body height, body weight, sensory disturbance, TSO, MWS at the start of CAGT (initial value : IV), and maximum isokinetic strength for knee extension from 90 to 0 degrees with an angular velocity of 30°/sec of the affected side (A-IK) as the independent variables.

$A = 0.973 \times \text{A-IK} + 71.203$ ($R^2 = 0.40$)

$B = 86.126 \times TSO + 5.358 \times \text{A-IK} - 291.552$ ($R^2 = 0.53$)

$2B/A = 1.405 \times TSO - 0.118 \times IV + 4.33$ ($R^2 = 0.81$)

The result of a regression analysis applied to the data of 91 patients indicates the following equation :

$2B/A = 1.552 \times TSO - 0.115 \times IV + 3.003$ ($R^2 = 0.955$)

With the solution of the equation, we can estimate the potential for walking capacity.

Figure 9 illustrates various hyperbolic curves, substituting different numbers into A or B. In the upper figure, parameter A is a fixed number 80. The larger the value of B is, the slower the improvement of walking speed. In the lower figure, parameter B is 321. Then, the larger the value of A is, the higher the attainable MWS and the better the recovery process.

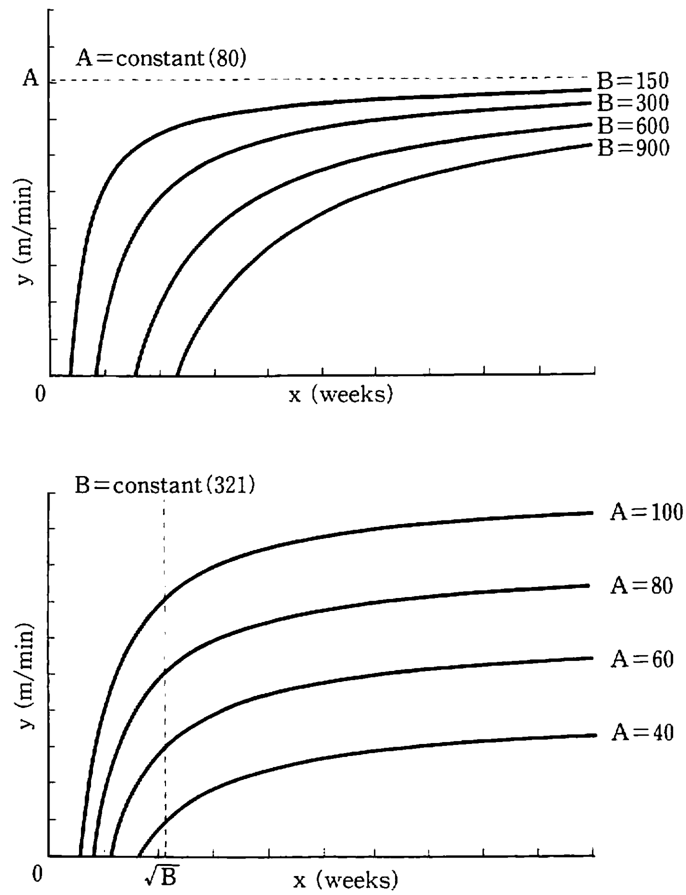

Figure 9 Various hyperbolic functions, y=A−B/x, substituting different numbers into A and B

(Nakamura et al. 1991)

[4] Prediction of Parameter A, B and 2 B/A at the Start of CAGT (Nakamura et al. 1992, 1997)

From January 1988 to February 1991, 385 stroke patients were admitted for medical rehabilitation to Narugo-Branch Hospital, Tohoku University School of Medicine. Among them 109 patients (28.3 %) were recruited as the subjects for the CAGT program based on following criteria : (1) they could walk without any walking aid at the start of physical therapy or attained the level of stable standing posture during the physical therapy ; (2) their MWS was below 100 m/min ; (3) their training program continued for more than 7 weeks after starting CAGT ; and (4) CT scan examination was performed before starting the medical rehabilitation.

A statistically significant approximation to the hyperbolic function was obtained in 91 patients, i. e., 83.5 % of the total sample population. From the data of 91 patients, the determinants of parameter A and B of hyperbolic function, $y=A-B/x$, and 2 B/A, the time at which MWS reached to A/2, were estimated using stepwise regression analysis. Since MWS is significantly related to age, the isometric muscular strength for knee extension and the body weight in healthy male subjects (Ito et al. 1989), and the isokinetic strength for knee extension of the affected side and the stability of standing balance in hemiparetic patients (Nakamura et al. 1985, Mojica et al. 1988, Nakamura 1991), the following eight variables were used as independent variables ; sex, age, height, body weight, TSO, MWS at the start of CAGT (IV), and isokinetic strength for knee extension of the affected (A-IK) and the non-affected side (N-IK) from 90 degrees flexed position to 0 degree with angular velocity of 30°/sec. Results revealed the following :

(1) the parameter A could be estimated by A-IK and IV ($R=0.657$, $R^2=0.423$),
(2) B was estimated by TSO and A-IK ($R=0.769$, $R^2=0.591$), and
(3) 2 B/A was predicted by TSO and IV ($R=0.977$, $R^2=0.955$) ;
$$2\,B/A=1.522\times TSO-0.15\times IV+3.003$$

The prediction of A and B is possible using the data of A-IK, MWS and TSO at the start of CAGT, although the accuracy of prediction is not so high. On the contrary, the prediction of 2 B/A, i. e., the time at which MWS reaches the half of its estimated highest value, is accurate and practically useful according to our experience.

The hyperbolic function reveals that a small 2 B/A corresponds with quick recovery of walking capacity and a large one with slow recovery. The multivariate analysis indicates that the longer the TSO and the slower the MWS at the start of CAGT, the longer 2 B/A is. These findings suggest that the recovery rate of walking capacity will depend upon the time elapsed from the stroke onset to the start of CAGT and also to the MWS at initial assessment.

[5] Whose Recovery is Most Predictable ? (Nakamura et al. 1992)

Using the data of 109 patients who underwent CAGT, we attempted to clarify the characteristics of a good candidate for CAGT, and also to find out the relationship between the typical recovery pattern of walking capacity and the localization of cerebral lesions. The characterisitcs of patients were obtained from the data base called 'RES (recovery evaluating system)' which stored demographic and neurological status and functional measures such as the Barthel index of every 4 weeks for all stroke patients admitted (Nakamura et al. 1990 b, 1991, 1999).

A significant approximation to the hyperbolic function was obtained in 91 patients (fit group), but not in the remaining 18 patients (non-fit group). Table 5 presents the demographic variables and the neurological impairments at the admission of the two groups. There were no statistically significant difference of age, TSO, height, body weight, and neurological impairments between the two groups. Table 6 shows A-IK and N-IK at the start of the CAGT and the MWS before and 7 weeks after

Table 5 Demographic variables and neurological impairments of the fit and the non-fit group at the admission. All variables are not statistically different between the two groups

	Fit (n=91)	Non-fit (n=18)
Age (years)	57.3[a]	58.7*
	(11.0)	(11.8)
Time since onset (weeks)	11.9	14.3*
	(5.9)	(5.7)
Height (cm)	159.7	156.7*
	(7.5)	(8.7)
Body weight (kg)	58.8	57.4*
	(7.7)	(8.2)
Sex (male : female)	66 : 25	12 : 6
Paretic side (left : right)	46 : 45	9 : 9
Diagnosis (SAH : CH : CI)[b]	3 : 41 : 47	1 : 5 : 12
Palsy		
(flaccid+ : −)	10 : 81	2 : 16
(spastic+ : −)	75 : 16	12 : 6
Sensory disturbance (+ : −)	48 : 43	8 : 10
Hemianopsia (+ : −)	12 : 79	1 : 17
Abnormal ocular movement (+ : −)	0 : 91	1 : 17
Nystagmus (+ : −)	0 : 91	1 : 17
Vertigo (+ : −)	2 : 89	0 : 18
Exaggerated tendon reflexes (+ : −)	90 : 1	18 : 0
Pathological reflexes (+ : −)	87 : 4	15 : 3
Dysphagia (+ : −)	3 : 88	1 : 17
Dysarthria (+ : −)	24 : 67	8 : 10
Aphasia (+ : −)	26 : 65	6 : 12
Ataxia (+ : −)	9 : 82	3 : 15
Involuntary movements (+ : −)	5 : 86	2 : 16
Urinary & bowel incontinence (+ : −)	5 : 86	1 : 17
Cognitive disorders (+ : −)	41 : 50	6 : 12
VIQ (≦59 : 60−79 : 80≦)	20 : 28 : 43	4 : 8 : 6
PIQ (≦59 : 60−79 : 80≦)	16 : 40 : 35	4 : 9 : 5

*t-test ; no marks, χ^2-test
[a]Values are expressed as the mean with S. D. in parentheses.
[b]SAH, subarachnoid haemorrhage ; CH, intracerebral haemorrhage ; CI, cerebral infarction ;
VIQ and PIQ, Wechsler Intelligence Score (V, verbal ; P, performance).

(Nakamura et al. 1992)

CAGT of the two groups. Compared to the non-fit group, MWS tended to be slow in the fit group at the start of CAGT, but its gain during 7 weeks was significantly large ($p<0.01$). CT scan findings were classified according to the presence or absence of pathological lesions on the frontal cortex, the cortex except the frontal lobe, the internal capsule, the basal ganglia, the thalamus, and the cerebellum and the brainstem, respectively (Table 7). The ratio between the patients with lesions of the frontal lobe and those without was significantly lower in the fit group than in the non-fit ($p<0.05$). On the contrary, the ratio of the patients with capsular lesions to those without tended to be high in the fit group. Table 8 presents the ratio of the patients between the fit and the non-fit group, based on the presence or absence of lesions of the internal capsule and the frontal lobe. The percentage of patients with significant hyperbolic curve fitting was highest in the dimension of capsular lesions

Table 6 The isokinetic strength for knee extension of the both sides at the start of CAGT, and the maximum walking speed before and 7 weeks after CAGT of the fit and the non-fit group

	Fit (n=91)	Non-fit (n=18)
A-IK (Nm)[a]	32.3[a]	30.7
	(31.3)	(27.9)
N-IK (Nm)	96.0	91.1
	(38.6)	(41.1)
MWS (m/min) : IV	30.7	42.1[+]
	(25.9)	(25.3)
MWS (m/min) : post	61.1	57.9
	(32.4)	(26.1)
MWS (m/min) : difference	30.4	15.7**
(post-IV)	(19.5)	(17.5)

IV : MWS at the start of CAGT, post : 7 weeks after CAGT
[a]Values are expressed as the mean with S. D. in parentheses.
$^{+}p<0.1$, $^{**}p<0.01$ (t-test).

(Nakamura et al. 1992)

Table 7 The number of patients classified into the two groups, with lesion (+) and without (−), by CT findings in the fit and the non-fit group

	Fit (n=91)	Non-fit (n=18)
CT findings	Lesion + : −	Lesion + : −
Frontal lobe	22 : 69	5 : 13
Cortex except frontal lobe	22 : 69	9 : 9*
Internal capsule	51 : 40	6 : 12[+]
Basal ganglia	44 : 47	8 : 10
Thalamus	19 : 72	3 : 15
Cerebellum and brainstem	4 : 87	2 : 16

$^{+}p<0.01$, $^{*}p<0.05$ (χ^2 test).

(Nakamura et al. 1992)

Table 8 The ratio of the patients between the fit and non-fit groups, divided by the presence (+) or the absence (−) of the cortical (except frontal) and the capsular lesions

		Cortical lesions (except frontal lobe)	
		+	−
Capsular lesion	+	5/3[a] (62.5/37.5)	46/3 (93.9/6.1)
	−	17/6 (73.9/26.1)	23/6 (79.3/20.7)

[a]x/y : x is the number of patients in the fit group and y is that in the non-fit. Values in parentheses are expressed in %.

(Nakamura et al. 1992)

(+) and cortical involvement except for the frontal lobe (−), suggesting that the recovery process of walking capacity was mostly typical and predictable in the patients with capsular lesions, frontal lobe lesions and an otherwise intact cortex. Demographic variables and neurological impairments did not discriminate the fit group from the non-fit. However, CT scan findings revealed that the presence of a capsular lesion without cortical lesions except the frontal lobe could be predictive of the recovery of MWS. Although the neurophysiological mechanisms of such recovery are not well understood, animal studies suggest that both the synaptic sprouting and unmasking, i. e., release from inhibition, may underlie those mechnisms (Stein et al. 1974, Finger 1978, Finger et al. 1988, Goldstein et al. 1990). The presence of an intact cerebral cortex would be a favorable condition for such structural reorganization after a damage of the internal capsule.

[6] Biomechanical Determinants and Predictors of the Maximum Walking Speed during CAGT (Suzuki et al. 1990, 1999 a, 1999 b)

Several studies have indicated that the speed of hemiparetic gait is related to the stability of standing balance and the muscle strength of lower extremities (Hamrin et al. 1982, Dettmann et al. 1987, Bohanonn 1989, Suzuki et al. 1990). However, the important biomechanical factors of hemiparetic gait and the factors that predict gait recovery during rehabilitation have not been elucidated. For instance, Goldie et al. (1999), trying to quantify the prediction of walking speed in ambulatory stroke patients during rehabilitation, concluded that a simple approach using initial walking speed, age, side of lesion and neglect as predictors for the walking speed 4 weeks later, was imprecise on an individual basis. In this study, we investigated the biomechanical determinants and predictors of MWS in hemiparetic patients within the first 3 months after stroke onset.

Thirty-four male patients participated in the study. They were recruited as the subjects for CAGT based on following criteria : (1) TSO was within 3 months, (2) they could walk over a 10 m distance without any aid at the start of CAGT, (3) their MWS was below 100 m/min, and (4) they could undergo CAGT 4 or 5 days every week for more than 8 weeks. MWS was recorded once a week. Quantitative measurements of standing balance, i. e., stability and postural control, were performed using a force measuring platform (9807 Y 9 system ; Kistler, Winterthur) and a personal computer. The subject stood on the center of the platform with eyes open and feet 10 cm apart. The position of the center of feet pressure (CFP) was determined every 10 msec for 10 sec and quantified as to its x and y values (Figure 10). The sway path (SP) was defined as the total length of the sway of CFP approximated by the sum of the distance between successive instantaneous two sampling points. The changes of CFP were measured while the subject shifted his body weight left and right, and held each position for 10 sec as much as possible. The percentage of the change of CFP in relation to the distance between the lateral margins of feet (LR%) was then calculated (Figure 11). In the same way, the changes of CFP while the subject shifted his body weight back and forth were measured, and the percentage of the change of CFP relative to the foot length (FB%) was calculated. The maximum isokinetic muscle strength for knee extension from 90 to 0 degrees with an angular velocity of 30°/sec of both the affected (A-IK) and the non-affected sides (N-IK) was measured with a dynamometer (Cybex II ; Lumex, NY). Three trials were performed with intertrial intervals of more than 30 sec. The highest value was used as data.

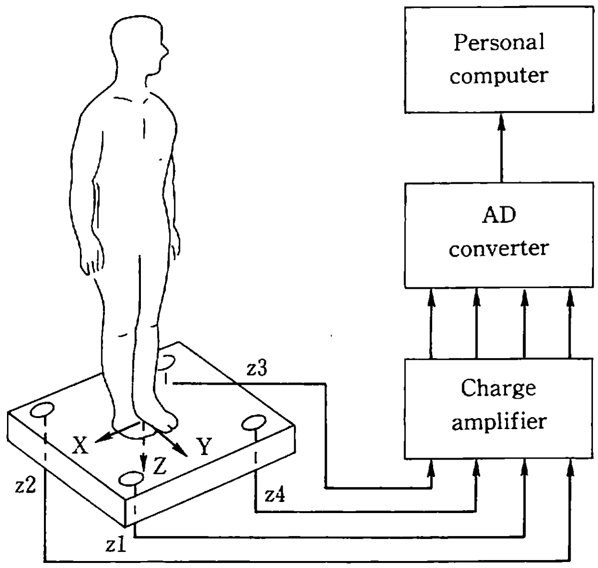

Figure 10 Schematic presentation of CFT and SP measurements
X : force X, Y : force Y, and Z : momentary center of feet pressure (CFP). The midposition of the force platform is taken as the zero point. The CFP is the center of distribution of the total force to the supporting surface. The momentary position of CFP is described by x and y coordinates calculated from the component vertical forces (z1, z2, z3 and z4) being recorded by each strain gauge : $CFPx = 4\,Dx\ \{(z1+z2)-(z3+z4)\}/(z1+z2+z3+z4)$; $CFPy = 4\,Dy\ \{(z1+z4)-(z2+z3)\}/(z1+z2+z3+z4)$ where Dx and Dy indicate the distance between strain gauges on the left and right columns as well as the fore and aft row, respectively. The position of the CFP is determined every 10 msec for 10 sec and quantified as to its x and y values. The sway path (SP) reflects the total length of the sway of CFP approximated by the sum of the distances between successive instantaneous two sampling points : $SP = \Sigma \sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)^2}$.
(Mojica et al. 1988)

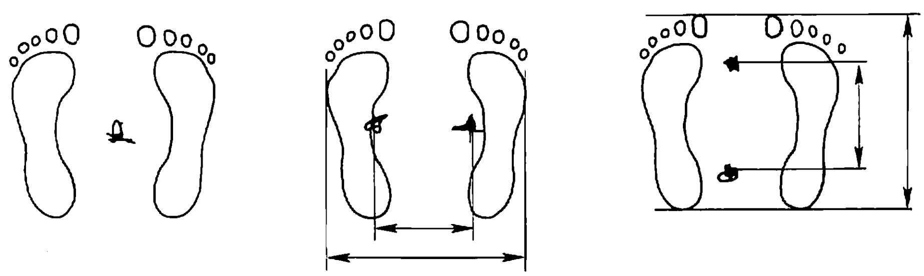

Figure 11 Measurements of standing balance
Sway path (SP) of the CFP in the upright position for 10 sec, the change of CFP while shifting body weight voluntarily in the left-and right direction (LR%), and the back-and-forth direction (FB%) are shown.
(Suzuki et al. 1999 b)

Table 9 shows the demographic and biomechanical variables at the start of CAGT, and 4 and 8 weeks thereafter. All variables improved 4 weeks after starting CAGT. Also, the means of the variables at 8 weeks improved significantly except SP, compared to those at 4 weeks. The mean MWS increased from 40.4 to 76.5 m/min for 8 weeks. The mean SP was over the upper limit of

Table 9 Characteristics and Variables of the Subjects

Characteristics			Mean (S.D.)	Range
Age (years)			54.2 (12.3)	28.0-81.0
Body height (cm)			160.9 (5.8)	148.3-174.1
Body weight (kg)			60.4 (7.0)	47.9-74.5
Time since stroke onset (weeks)			8.6 (3.0)	1.6-13.8
Variables	Start	Range	4 weeks	8 weeks
MWS (m/min)	40.4 (28.6)	4.6-98.4	63.2 (33.0)*	76.5 (31.1)*
SP (cm/10 sec)	34.6 (13.9)	17.1-76.5	28.3 (7.5)*	27.0 (6.9)
FB%	13.4 (9.4)	0.8-31.6	17.9 (13.0)*	20.4 (13.4)
LR%	24.0 (14.6)	1.9-55.6	31.1 (13.1)*	36.4 (14.8)*
N-IK (Nm)	115.8 (33.8)	73.0-211.0	127.1 (32.4)*	134.9 (36.0)*
A-IK (Nm)	39.7 (30.2)	0.0-130.0	52.5 (37.6)*	60.1 (41.0)*

Variables reported as mean (SD) .
*$p<.01$.

(Suzuki et al. 1999 a)

Table 10 Determinants of the Maximum Walking Speed

Regression Equation	Standard Regression Coefficient	R^2
At the start		
$MWS_0 = 8.654 + 1.324 \times LR\%_0$	.674	.454
At 4 weeks		
$MWS_4 = 26.761 + .695 \times A\text{-}IK_4$	.793	.629
At 8 weeks		
$MWS_8 = 42.847 + .560 \times A\text{-}IK_8$	.738	.545

MWS_0 denotes MWS at 0 week, and so on.

(Suzuki et al. 1999 a)

normal range, i. e., 30 cm/10 sec, at the start of CAGT, but decreased to within the normal range after 4 weeks. MWS was significantly related to SP, LR%, FB%, A-IK and N-IK during CAGT for 8 weeks. Stepwise regression analyses were performed using MWS as the dependent variable, and age, body height, body weight, TSO, SP, LR%, N-IK and A-IK as the independent variables (Table 10). At the start of CAGT, LR% was the only determinant of MWS. At 4 and 8 weeks respectively, the determinant was A-IK. MWS at 4 and 8 weeks was significantly related to MWS, SP, LR%, FB%, A-IK and N-IK at the start of CAGT. Table 11 presents the regression equation of MWS. Stepwise regression analyses revealed that the main predictor at 4 weeks was the initial MWS (IV), followed by A-IK and TSO. At 8 weeks the main predictor was IV, followed by A-IK. The results suggest that the MWS at 4 and 8 weeks after starting CAGT could be predicted by MWS, A-IK and TSO at the start of CAGT with high coefficients of determination.

Table 11 Predictors of the Maximum Walking Speed

Regression Equation	Standard Regression Coefficient	R^2
At 4 weeks		
$MWS_4 = 35.88 + .649 \times MWS_0$	.564	
$+ .488 \times A\text{-}IK_0$	.447	.843
$- 2.112 \times TSO$	−.192	
At 8 weeks		
$MWS_8 = 36.30 + .620 \times MWS_0$	.570	.734
$+ .382 \times A\text{-}IK_0$	.371	

(Suzuki et al. 1999 a)

[7] Successive Changes of the Maximum Walking Speed, the Sway Path and the Isokinetic Muscle Strength for Knee Extension during CAGT (Nakamura et al. 1997)

MWS, SP, A-IK, and N-IK were examined once a week or twice a month successively in 32 stroke patients aged 23 to 72 years old.

Based on MWS at the last measurement, the patients were divided into two groups (Table 12), 19 patients belonging to group A (good recovery) and 13 to group B (poor recovery). In group A, the MWS increased beyond 30 m/min and SP were within 30 cm/10 sec during successive measurements, whereas the MWS remained below 30 m/min and SP above 30 cm/10 sec in Group B (Table 13, 14). Statistically significant determinants of good recovery of MWS at the early phase of gait training were N-IK, SP, age and TSO. Compared to the patients with poor recovery of MWS, those with good recovery had larger N-IK, smaller SP and shorter TSO, and were relatively younger. Using the data of group A, we calculated the period between the date when MWS exceeded 30 m/min and when SP became lower than 30 cm/10 sec. The mean period was 1.2 ± 3.3 weeks, suggesting that there was no statistically significant difference in the time of appearance of the changes. SP within the upper limit of normal range (30 cm/10 sec) would be indispensable for the independent gait (MWS above 30 m/min) of stroke patients. In the early phase of gait training for hemiparetic patients, improvement of the stability of station leads to a substantial gain of MWS.

Table 12 Characteristics of the two groups at the initial measurement

	Group A	Group B	
Sex (male : female)	16 : 3	8 : 5	ns
Age (years)	45.5 (11.5)	56.9 (8.9)	**
Paretic side (left : right)	10 : 9	4 : 9	ns
Time since onset (weeks)	13.8 (5.9)	18.2 (5.8)	*
Sway path (cm/10 sec)	38.5 (6.9)	49.0 (15.0)	*
A-IK (Nm)	17.0 (19.8)	2.2 (2.8)	*
N-IK (Nm)	93.7 (25.8)	66.7 (21.0)	**

( ) : S. D. $^{*}p<0.05$, $^{**}p<0.01$

Table 13 Walking speed of the two groups

	Group A	Group B	
Duration of observations (weeks)	15.3 (5.3)	13.8 (6.0)	ns
Number of measurements	8.4 (4.9)	8.1 (4.8)	ns
Initial walking speed (m/min)	12.4 (5.4)	8.2 (4.2)	*
Last walking speed (m/min)	56.6 (24.2)	15.7 (6.3)	**
Gain of walking speed (m/min/week)	3.1 (2.3)	0.5 (0.5)	**

( ) : S. D. *$p<0.05$, **$p<0.01$

Table 14 Biomechanical variables at the initial and the last measurements

	Group A		Group B	
	initial	last	initial	last
SP (cm/10 sec)	38.5 (6.9)	24.1 (4.1)	49.0 (15.0)	38.0 (10.2)
A-IK (Nm)	17.0 (19.8)	32.5 (21.0)	2.2 (2.8)	6.6 (7.7)
N-IK (Nm)	93.7 (25.8)	117.9 (41.3)	66.7 (21.0)	74.3 (19.4)

( ) : S. D.

[8] Factors Affecting the Recovery of Maximum Walking Speed in Stroke Patients
(Nagasaki 1992)

Clinical experience indicates that as regards the recovery of walking capacity after stroke, there is a wide range of individual difference among patients in a few months after starting gait training (Mizrahi et al. 1982, Winstein et al. 1989, Nakamura et al. 1992). Then a question arises as to which demographic variables including neurological impairments are relatively simple predictors of the recovery of walking capacity. As for gait and/or motor function of the lower extremity, several variables are reported as predictors, e. g., initial walking speed, age and early admission to rehabilitation hospital (Gowland 1982, Friedman 1990, Mayo et al. 1991, Nakamura et al. 1991).

The recovery of MWS was examined in stroke inpatients during 8 weeks of physical therapy. Motor functions, neurological impairments, and age of the patients were considered as factors affecting the recovery. Data of 81 patients aged 28 to 81 years old were obtained from the data base 'RES (recovery evaluating system).' The TSO ranged from 11 to 166 days. The patients could walk at least with walking aids, and underwent CAGT for 8 weeks at Narugo-Branch Hospital, Tohoku University School of Medicine. A factor analysis after a promax rotation was performed on 22 neurological signs and symptoms at the time of admission, which classified those variables into five nearly independent factors ; HEMIPLEGIA, SENSORY disturbance, muscle TONE, ATAXIA and disorders of COGNITION. Biomechanical variables related to walking capacity, i. e., A-IK, N-IK, SP, LR% and FB%, were also factorially analyzed and represented by three independent factors, namely : muscle strength of the affected (A-MUSCLE) and the non-affected (N-MUSCLE) lower extremity, and postural STABILITY. MWS was measured at the start of CAGT and 8 weeks later. The difference of MWS between the two measures was regarded as the recovery of walking speed during the past 8 weeks. A path-analysis model was designed in order to analyze the possible causal relationships between the recovery of walking capacity and neurological impairments, motor func-

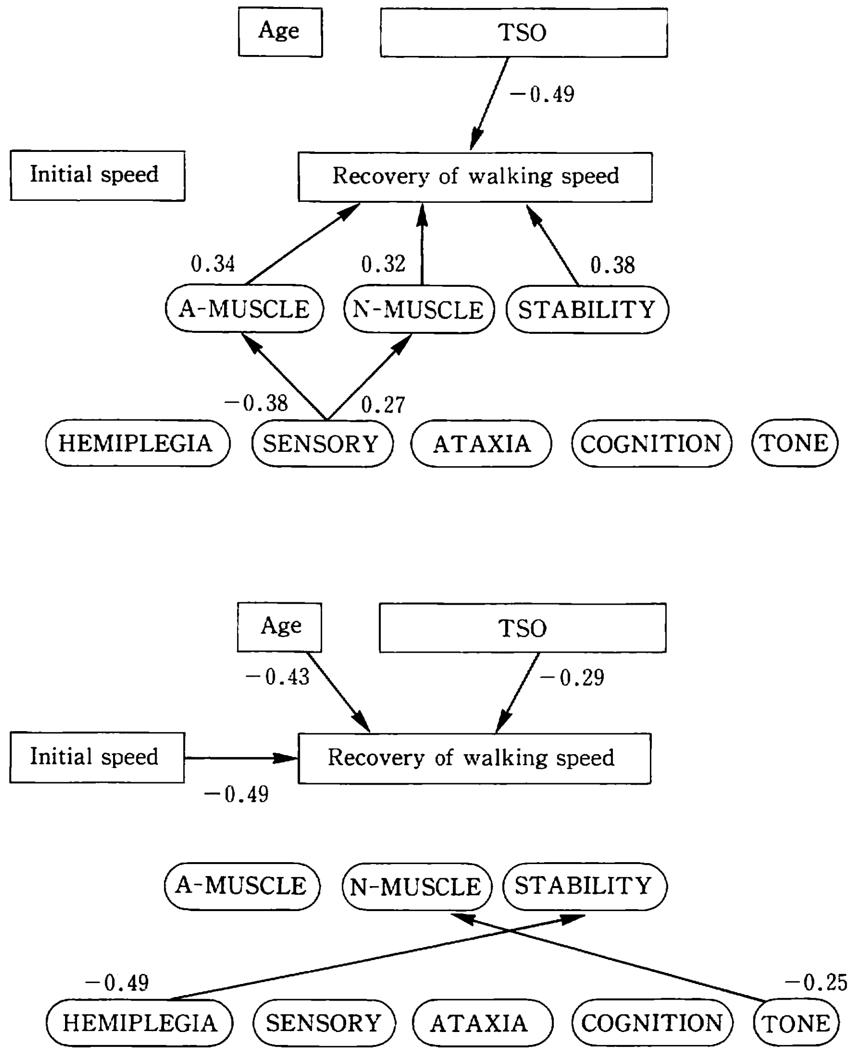

Figure 12 The path-analysis model of the recovery of maximum walking speed during 8 weeks, and path coefficients obtained for 81 patients

Upper figure : patients with the maximum walking speed below 50 m/min at admission ($R^2=0.55$).

Lower figure : patients with the maximum walking speed above 50 m/min ($R^2=0.33$).

(Nagasaki 1993)

tion and age. In Figure 12, neurological impairments are represented by scores of five factors and impaired motor function by three factors, as shown by the labels each enclosed by an oval. It was assumed that the recovery was determined by motor functions and neurological impairments directly, and also by the impairments indirectly through their influence on motor functions. Age and TSO might affect the recovery independently. MWS at the start of CAGT, which was also related to every demographic, neurological and motor conditions, could influence the recovery of walking capacity during CAGT.

The patients were divided into two groups : one group with MWS less than 50 m/min and the other group was composed of patients with MWS greater than 50 m/min at the start of CAGT. In Figure 12, the path coefficients above 0.2 are superimposed on the model for the two groups. For 45 patients

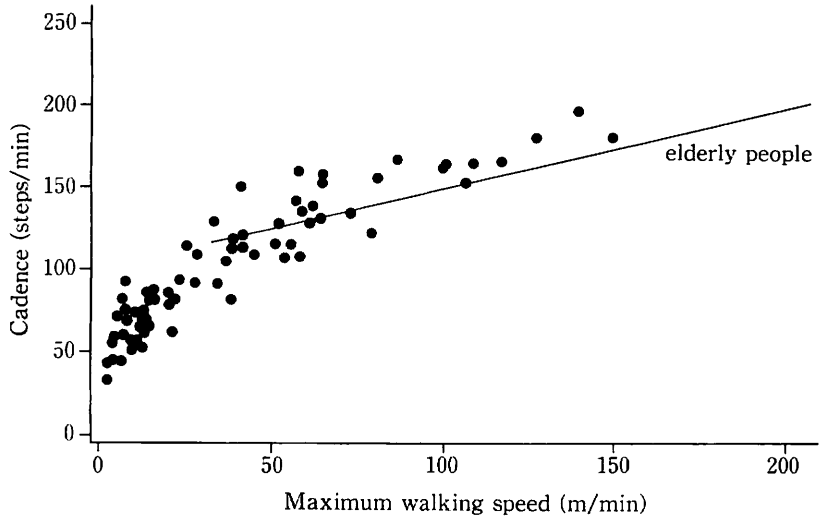

Figure 13 Relation of the maximum walking speed to the cadence
Data were obtained from 81 stroke patients at admission. The relation of maximum walking speed to cadence for community-living elderly people is shown by the regression line.

with MWS less than 50 m/min, all of the motor function factors had a direct effect on the recovery of walking capacity, and TSO had a negative effects on the recovery. That is, the longer the TSO, the lesser the recovery of walking capacity is. The initial MWS and age had no effect on the recovery of this group. In contrast, the results of the path-analysis of 36 patients with MWS greater than 50 m/min showed that both neurological impairments and impaired motor functions were not related to the recovery. Instead, the age of the patients had a negative impact on the recovery. A negative path coefficient from the initial MWS to the recovery of walking capacity suggested that patients with higher MWS showed relatively less recovery during subsequent CAGT. The results of this analysis indicate that the recovery of walking capacity in patients with MWS below 50 m/min is under the direct impact of neurological impairments, whereas the recovery of patients with MWS above 50 m/min is related to their age. The relationship between MWS and cadence at the start of CAGT is shown in Figure 13. The same relationship for 392 elderly people living independently in the community is also presented in the figure. The cadence is linearly related to MWS for the patients with MWS greater than 50 m/min, and this relationship is not different from that of elderly people without stroke. Figure 13 also suggests that MWS of stroke patients is mostly determined by their age after MWS recovered beyond 50 m/min. It is important for medical rehabilitation of stroke patients to enhance their walking capacity so as to be able to walk at MWS greater than 50 m/min, and improving muscle strength of the both lower extremities and postural stability are prerequisites for this purpose.

[9] Effect of Ankle-Foot Orthosis (AFO) on Body Sway and Walking Capacity
(Mojica et al. 1988, Nakamura 1991)

Previous studies have shown that in hemiparetic patients, the greater the body sway or postural instability at station was, the poorer the walking capacity (Dettmann et al. 1987, Nakamura et al. 1988 b). Bohannon et al. (1984) and Bohannon (1987), measuring the ability to balance with the eyes open or closed and the feet together in normal subjects 20 to 79 years old and in hemiplegic patients, reported that dysfunction of balance was strongly related to age and walking capacity, i. e., the balance decreased with age and that as the balance improved, so did the walking capacity. Hemispheric lesions of stroke patients could bring about dysregulation of posture, balance and gait, producing instability in standing posture. Peripherally, weakness of the affected lower extremity as well as mediolateral instability of the ankle joint would increase body sway and hinder gait performance (Perry 1969, Nakamura et al. 1985, Lehmann et al. 1987, Nakamura et al. 1988 b). The use of ankle-foot orthosis (AFO) promotes ankle and foot stability, and improves gait performance of hemiparetic patients (Lehmann 1979).

The effect of AFO on SP and MWS was analyzed in eight hemiparetic patients, five with the right hemiparesis and three with the left hemiparesis, aged from 46 to 66 years. TSO to the examination was 7 to 32 weeks (mean : 20.7 weeks). The affected lower extremity showed mild to moderate muscular hypertonia, but passive range of motion was within the normal limit in all patients. The patients could stand alone and have used plastic AFO for mean duration of 7.5 weeks (range : 2 days-18 weeks). Wearing AFO (AFO(+)) and without (AFO(−)), i. e., barefoot, the patient was instructed to stand on the force platform with the head upright, eyes open and looking forward, arms at the sides and the feet together equidistand from the platform edges in the fore-aft and lateral positions, respectively. The patient was asked to maintain the posture more than 10 sec, during which the measurement was performed. In addition, the patient was asked to walk 10 m distance as fast as possible with or without AFO.

Figure 14 shows the SP without and with AFO in a right hemiparetic patient. When barefoot, the center of feet pressure (CFP) moves forward and left of the midposition towards the non-affected side. Wearing AFO, CFP maintains its forward position but moves medially close to the midposition.

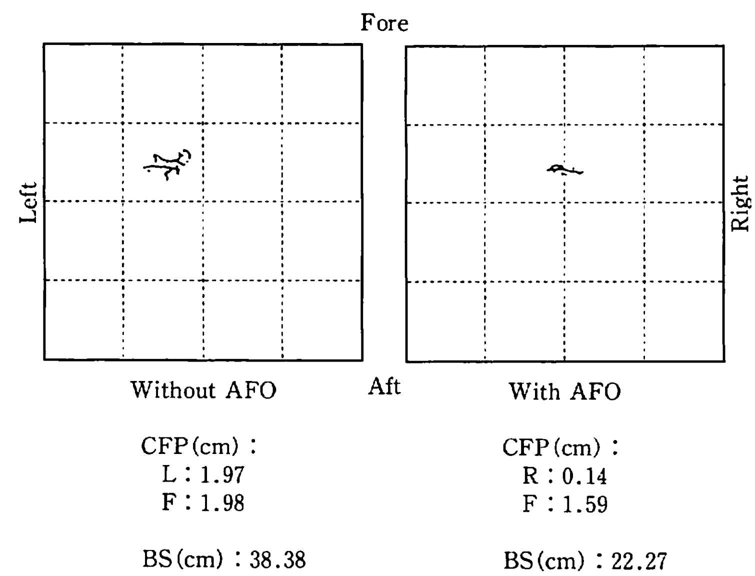

Figure 14 Computer display of the sway path (SP) in a right hemiparetic patient without and with AFO

Distance between divisions is 2.5 cm.

L : left, R : right, and F : fore.

(Mojica et al. 1988)

Table 15 Means and standard deviations (in parenthesis) of the mean positions of the lateral and fore-aft components of CFP and SP without and with AFO

	CFP (cm)		SP (cm/10 sec)
	Lateral (paretic/ non-partetic)	Fore-aft	
AFO (−)	2.42 (1.37)	2.36 (1.07)	37.93 (14.48)
AFO (+)	1.56 (1.08)	2.08 (0.90)	28.96 (9.77)
Difference	0.86 (0.96)	0.28 (0.66)	

AFO (−) , without AFO ; AFO (+), with AFO.
n=8 (Mojica et al, 1988)

Table 16 Means and standard deviations (in parenthesis) of the variables of gait components without and with AFO

	Walking speed (m/min)	Cadence (steps/min)	Stride length (m)
AFO (−)	32.80 (24.94)	91.78 (25.42)	0.64 (0.35)
AFO (+)	41.58 (30.57)	102.56 (25.77)	0.74 (0.39)

AFO (−), without AFO ; AFO (+), with AFO. (Mojica et al. 1988)

Table 15 presents the means of lateral and fore-aft components of CFP as well as SP without and with AFO. Compared to without AFO, a significant reduction was observed in the lateral component of CFP when using AFO ($P<0.05$), but not in the fore-aft component. The shift of CFP towards the non-paretic side pointed out a greater weight supporting activity borne by the non-paretic side, compared to the paretic side. Wearing AFO compensated for the instability of the ankle joint, promoted steadiness when standing, and allowed the shift of part of the body weight onto the affected side. There was a significant difference in SP between the with and without AFO conditions ($p<0.01$), indicating that with AFO, SP decreased with improved standing balance. Table 16 shows the means of gait components of the patients. Each component was improved with AFO ($p<0.01$, respectively). AFO compensated for the mediolateral instability of the ankle joint, prevented foot drop and decreased the degree of hip-hiking during swing phase. The mean ratio AFO (+)/AFO (−) of each variable was calculated. The mean ratio of SP relative to the mean ratio of MWS, cadence and stride length showed no correlation, respectively. The reduction of SP was not related to the gain of gait components when wearing AFO, indicating the disturbances in balance and gait due to stroke reflected disorders of both central and peripheral mechanisms. AFO improved peripheral stability, but did not correct the dysfunction of the central nervous system. The contribution of either central or peripheral factor to the impaired balance and gait was different for each patient.

[10] Pharmacological Approaches to Enhance Motor Recovery (Nakamura et al. 1990 a, Nakamura 1991)

Pharmacological approaches have been tried to enhance motor recovery after cerebral insults in both animal experiments and clinical studies (cf. Bach-y-Rita et al. 1988). Norepinephrine agonists accelerate recovery of motor function and its angtagonists retard or reinstate motor deficits (Feeney et al. 1982, Hodva et al. 1984). According to a pilot study examining the effect of amphetamine, a precursor of norepinephrine, on motor recovery of stroke patients, a single dose of amphetamine combined with physical therapy increased the motor recovery as compared with results in patients receiving physical therapy alone (Davis et al. 1987). Post-training administration of epinephrine influences retention of several types of learning tasks in animals (McGaugh 1987). Feeney et al. (1982) examined the effect of amphetamine on the locomotive function of animals with cortical lesions. The group of rats administered amphetamine at 24 hours after brain injury showed rapid recovery compared to those given saline. Restraint of body movements during drug intoxication blocked this effect. However, no significant differences were found in final locomotive function between the two groups. The results suggested that elevation of the arousal state induced by amphetamine facilitated efficiency of physical exercises reducing the time necessary for functional recovery. It is not clear whether the effect is due to the elevated arousal or not, since the performance of neurological patients is closely related to the arousal state. Trueblood et al. (1989), examining the effect of 15 min PNF (proprioceptive neuromuscular facilitation) based pelvic exercise on stability and advancement of lower extremity in hemiparetic patients, reported that the improvements immediately after treatment did not carry over 30 min after. It is well known that PNF brings about EEG and behavioral arousal, resulting in transient improvement of performance (Nakamura et al. 1983 a, 1986). Thyrotropin releasing hormone (TRH), an agonist of norepinephrine, has been ascertained to facilitate functional recovery, acting on elevation of the arousal state via biological monoamine systems (Keller et al. 1974). For instance, a series of 2 mg of TRH administration to stroke patients for 10 days shortened both hospital stay for medical rehabilitation and periods required for improvement of social skills (Chida et al. 1987).

The effect of TRH on SP, A-IK, N-IK and MWS was examined in 7 hemiparetic patients. Measurements of biomechanical variables were performed before and 10 to 20 min after 2 mg-TRH intravenous administration. Table 17 presents the means of the variables examined. A-IK increased and SP decreased significantly after TRH administration, resulting in the increase of MWS. However, N-IK was not influenced by TRH, suggesting that the effect of TRH was specific. The gain of walking speed during the CAGT program was larger in patients with EEG arousal response induced by physical stimulation than in those without EEG arousal (Seki et al. 1990). This report supports the notion that norepinephrine agonists accelerate motor recovery including walking capacity after stroke.

Table 17 Means of the biomechanical variables before and after TRH administration.

Variables	Before	After	Difference
A-IK (Nm)	81.1 (77.6)	84.1 (78.4)	2.8 (2.8)*
N-IK (Nm)	140.4 (67.6)	141.3 (68.6)	0.9 (8.5)
SP (cm/10 sec)	26.8 (13.9)	20.8 (7.9)	−6.0 (6.1)*
Walking speed (m/min)	81.9 (49.0)	84.0 (48.0)	3.1 (1.8)*

( ) : S. D.
A-IK : isokinetic strength of the affected side, N-IK : isokinetic strength of the non-affected side, and SP : sway path. n=7, *$p<0.05$.

(Nakamura et al. 1990 a)

3 POSTSCRIPT

[1] Application of CAGT for Patients with Traumatic Brain Injury (Nakamura et al. 1994)

Thirteen patients with traumatic brain injury (TBI) underwent CAGT, and the relationship of the time since TBI onset to the maximum walking speed (MWS) was presented in terms of a coefficient of hyperbolic function. Statistically significant approximation was seen in 10 patients with the MWS below 100 m/min at the start of CAGT ; fit group. The MWS was above 100 m/min in three patients without significant curve fitting : non-fit group. The gain of MWS in the fit group, 3.8±2.7 (mean± S. D.) m/week, was definitely high, compared to those of the non-fit group, 0.9±0.8 m/week. The results favor the applicability of CAGT to patients with TBI.

[2] Applicability of the Approximation to Hyperbolic Function for Stroke Patients Walking with Gait Aids (Kawai et al. 1995)

Canes or crutches are prescribed for stroke patients with impaired balance, preferably only for temporary use. We tested the applicability of the approximation to hyperbolic function, when the patient walks with gait aids such as T-cane and quadricane. Fifteen patients aged from 29 to 67 (mean : 46.9) years participated in the study. The time since stroke onset (TSO) ranged from 17.1 to 74.1(mean : 32.6) weeks. The maximum walking speed (MWS) with a cane was examined usually once a week for more than 5 times. Statistically significant approximation was obtained in 10 patients (fit group) and not in 5 patients (non-fit group). The TSO was shorter in the fit group (mean±S. D. : 23.1±5.6 weeks) than in the non-fit (51.6±17.4 weeks). The longest TSO of a patient belonging to the fit group was 33.7 weeks. MWS at the start of CAGT was low in the fit group (17.5±12.5 m/min), compared to the non-fit (37.0±17.2 m/min). There was no significant difference between the two groups in age, height, body weight, etiology and pathology of stroke, affected side, lesions on CT images, presence of sensory disturbance and neglect, and braces prescribed. The results imply that CAGT could be applicable for patients using canes, when their TSOs are within 33 weeks.

[3] Relation Between Walking Capacity and Daily Life Activities of Stroke Patients Living Home (Sajiki et al. 1991)

Daily life activities of stroke patients are influenced by their physical and mental impairments, family structure and physical environments. For instance, walking capacity is one of the most important factors to predict daily life activities in stroke patients (Sajiki 1980).

The relationship of MWS to performance of daily life activities were analyzed by using a 75-item questionnaire in 54 ambulatory stroke patients more than one year after discharge. The daily life activities questionnaire is composed of 10 categories : work (number of items : 1-6), housework (7-16), child care (17-24), purchase of goods and services (25-30), personal needs (31-36), adult education and professional training (37-42), civic and collective participation activities (43-49), events, entertainment and social life (50-57), sports and active leisure (58-66), and passive leisure

(67-75) (Nakamura 1983 b). The patient was asked on the his/her performance for the 75 items during the past year. The patient's answers were tallied using the following scoring system : 0=not doing, 1=doing a few times annually, 2=doing monthly, 3=doing weekly, and 4=doing almost everyday. Multivariate discriminant analysis of quantitative data (Hayashi's quantification I) was performed to clarify the difference between 'doing' and 'not-doing' of 75 items using six independent variables ; age, sex, paretic side, TSO, MWS, and position in the family.

The mean MWS was 56.3 (range : 7.4−161.3) m/min, and MWS was below 20 m/min in three patients and above 80 m/min in 10 patients. MWS was the most significant discriminant of 27 items. The self-care activities and static activities such as reading a newspaper were not related to MWS. Most patients with MWS greater than 20 m/min performed several home and leisure activities such as learning, shopping, hobby and traveling. Those with MWS greater than 40 m/min did some adult education such as attending professional or special training courses or art work, and visiting museums. Patients with MWS greater than 60 m/min did some social activities such as participation in a meeting of party or union, while those with MWS greater than 80 m/min took care of family members as part of their home chores. An individual's walking speed and distance are related to his/her social and physical environments (Finley et al. 1970, Lerner-Frankel et al. 1986, Robinett et al. 1988). It seems that MWS is a reliable predictor of performance of daily life activities in ambulatory stroke patients.

[4] Relation of the Maximum Walking Speed to the Speed of Free Walk in Stroke Patients (Yamada et al. 1990)

There is a statistically significant correlation between MWS and the speed of 3 minutes free walk in stroke patients. Accordingly, we can estimate walking speed of stroke patients in daily life, using the following equation.

$y=0.45x+8.9 \quad r=0.93,\ p<0.01.$

x : MWS, y : the speed of 3 minutes free walk.

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