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Gait parameters following stroke: A practical assessment

Herbert P. von Schroeder, MD; Richard D. Coutts, MD; Patrick D. Lyden, MD; Edmund Billings Jr., MD; Vernon L. Nickel, MD

The Department of Orthopaedics and Rehabilitation and the Department of Neurosciences, University of California, San Diego, CA 92103-1190; M & D Coutts Institute for Joint Reconstruction and Research, San Diego, CA 92123; Department of Veterans Affairs Medical Center, San Diego, CA 92161

Abstract—Mechanical methods of quantifying gait are more sensitive to change than is direct clinical inspection. To assess gait parameters and patterns of patients with stroke, and the temporal changes of these parameters, a foot-switch gait analyzer was used to test 49 ambulatory patients with stroke and 24 controls. Patients walked significantly slower than controls, with decreased cadence, increased gait cycle, and increased time in double limb support. Patients' hemiplegic limbs spent more time in swing and stance when compared to controls; their unaffected limbs spent significantly more time in stance and single limb support compared to controls. Patients' hemiplegic side, when compared with the unaffected side, spent less time in stance and more time in swing. A flatfoot pattern was typically noted on the affected side. General gait parameters improved over time, with the largest changes occurring in the first 12 months. However, the percentage of time spent in double and single limb support, stance and swing, parameters which describe the asymmetrical pattern of gait, did not change over time. Abnormal gait was due to difficulty in moving the body over an unstable limb. Gait analysis can be of importance in documenting abnormalities and determining the effects of therapeutic modalities.

Key words: *functional recovery, gait, gait analysis, hemiplegia, rehabilitation, stroke, walking cycle.*

INTRODUCTION

Ambulation is a significant part of the functional recovery following stroke and depends on several factors, including size and location of the infarct (1) and premorbid health. Quantitated gait analysis may be useful in monitoring gait performance and functional recovery following stroke (2–6); however, gait patterns are quite variable (1,4,6). Such variability has been described for velocity, cadence, stride length, and patterns of asymmetry (5,7,8), even in a clinically homogeneous group (6). It has been recognized that certain gait parameters following a stroke will mirror a patient's overall functional recovery. Patients who survive strokes have shown improvement in gait velocity, cadence, stride length, step length, stride time, single limb support, and stance over time (5,9–12), with most improvement occurring in the first 3 months following the stroke (5,10). Our purpose was to quantify and describe the gait of patients with stroke, using a practical gait analyzer and assess the temporal changes of these parameters.

SUBJECTS AND METHODS

Forty-nine patients with stroke were assessed and compared with 24 age-matched controls. The patients were all functionally ambulant, had a mean age of 64.2 years and were on average 43.4 months post-stroke (range 0.5–336 months). Of the 49 patients, 9 had no hemiplegia and 2 had bilateral symptoms; these 11 patients were therefore analyzed separately. Of the 38 hemiplegic patients, 10 were assessed at two different times during their rehabilitation: these were treated as independent observations for a total of 48 assessments (**Table 1**). Control patients had either transient ischemic episodes (TIA) or asymptomatic carotid stenosis and had normal physical examinations and symmetrical gait without the use of walking aids. All patients

Address all correspondence and requests for reprints to: H.P. von Schroeder, MD, Division of Orthopaedics, Mount Sinai Hospital, 600 University Ave., #476A, Toronto, Ontario, Canada, M5G 1X5.

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Table 1.
Patient Characteristics.

	All Stroke Patients	Hemiplegic Patients	No Symptoms	Bilateral Symptoms	Control
Number	59	48	9	2	24
Male (%)	90	90	89	100	88
Female (%)	10	10	11	0	13
Age	64 ± 10	65 ± 10	61 ± 15	59 ± 4	64 ± 10
	[30–82]	[4–82]	[30–73]	[24–79]	[24–79]
Months since stroke	43 ± 70	46 ± 77	33 ± 28	26 ± 15	—
	[0.5–336]	[0.5–336]	[2–72]	[15–36]	
Assessment:					
0–3 mos	14	13	1	0	—
> 3–12 mos	10	7	3	0	—
> 12–36 mos	11	7	2	2	—
> 36 mos	24	21	3	0	—
Assist/Orthoses	19	19	0	0	0
cane	12	—	—	—	—
ankle/foot orthosis	7	—	—	—	—
walker	2	—	—	—	—
assistant	2	—	—	—	—
rail	1	—	—	—	—
Side					
right	34	34	—	—	—
left	14	14	—	—	—
bilat	2	—	—	2	—
neither	9	—	9	—	—

Mean ± 1 SD, [range].

and control subjects were free of any other medical problems which interfered with gait.

Gait was analyzed using a portable stride analyzer (B & L Engineering, Santa Fe Springs, CA). The device consisted of insoles which contained four compression-closing foot switches in the heel, first and fifth metatarsal, and great toe regions. When placed in the subject's shoes, the insoles were connected to a lightweight mobile data collection box worn on a belt. Subjects walked on an 18-meter thinly carpeted hallway, and data were collected over the middle 6 meters, delineated by photoelectric cells. The data were transferred to a personal computer for analysis of comprehensive and unilateral gait parameters. Comprehensive parameters were measurements determined from both legs; these included gait velocity (meters/sec), cadence (steps/min), stride length (distance from heel strike to heel strike of the same leg, in meters), gait cycle (time in seconds from heel strike to heel strike of the same leg), and total double limb support (duration of time that both limbs were on the ground per cycle, in seconds and as a percentage of gait cycle). Unilateral parameters which were determined for each limb individually, included: single limb support (duration of time one leg was on the ground by itself, in seconds and as a percentage of gait cycle), duration of swing phase (time a single limb was not on the ground, in seconds and as a percentage of gait cycle), and stance phase (total time single limb was on the ground, in seconds and as a percentage of gait cycle). A typical gait printout illustrating the gait parameters and footprint pattern is shown in **Figure 1.** Footprint patterns displayed the relative amount of time spent on four regions of the foot. Gait parameters were compared between patients with stroke and controls using an unpaired two-tailed Student's t-test (significance at $\alpha < 0.05$).

Patients were divided into four subgroups based on time from stroke: (a) less than 3 months post-stroke, (b) 3 to 12 months, (c) 12 to 36 months, and (d) greater than 36 months post-stroke. To test reproducibility of the gait

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ID NUMBER:              AGE:        48
DATE:                   SEX:        M
DIAGNOSIS: R-CVA        TEST CONDITIONS: CANE
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BILATERAL PARAMETERS	ABS.	%NORMAL
VELOCITY (M/MIN):	25.8	29.2
CADENCE (STEP/MIN):	59.4	53.5
STRIDE LENGTH (M):	0.868	54.2
GAIT CYCLE (SEC):	2.02	187.1
DOUBLE LIMB SUPPORT (%GC):	35.0	

UNILATERAL PARAMETERS	RIGHT	LEFT
SINGLE LIMB SUPPORT		
(SEC):	0.872	0.446
(%NORMAL):	102.5	52.4
(%GC):	43.2	22.1
SWING (%GC):	22.1	43.2
STANCE (%GC):	77.9	56.8

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FOOT-PRINT PATTERN vs. TIME
H = HEEL   T = GREAT TOE   1 = 1ST METATARSAL   5 = 5TH METATARSAL

R
I 55555555555555555555                                      555555555555555555555
G HHHHHHHHHHHHHHHHHHHHH                                 HHHHHHHHHHHHHHHHHHHHHHHHH
H         11111111111111                                            111111111111111
I        TTTTTTTTTTTTTTT                                           TTTTTTTTTTTTTTT
L                                                     TTT
E                                            111111111111
F              HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH                    HHHHHHHHHHHHHHHHHHHHHI
T                             5555555555555555555555555555                        5555!

^                        ^                        ^                        ^
0                        1                        2                        3
SEC                      SEC                      SEC                      SEC
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Figure 1.
Sample gait analysis printout illustrating gait parameters and footprint pattern. This stroke patient had a typical gait pattern characterized by decreased velocity, cadence, and stride length. The patient's weaker left leg spent less time in single limb support and more time in stance. The converse was true for his normal right leg. The footprint pattern shows an abnormality of the left foot with the heel and fifth metatarsal regions striking the ground at the same time and lifting of the entire foot at once instead of a normal progression from the back to the front of the foot. The right footprint is normal in appearance except that it is elongated due to an increased amount of time spent on this normal side.

analyzer, two control subjects and five patients with stroke each walked twice in sequence. The pair of analyses for each patient were then compared.

RESULTS

The age of patients with stroke was comparable to the control group ($p = 0.97$). In two patients, gait was characterized by dragging both feet and hence only velocity could be determined over the length of the walk. The comprehensive gait parameters of all other patients ($n = 57$) were compared to the control group and are summarized in **Table 2.** Hemiplegic patients walked significantly slower than controls ($p < 0.0001$), with decreased cadence ($p < 0.005$), increased gait cycle ($p = 0.02$), and a slightly shorter stride ($p = 0.07$); however, the stride length did not reach statistical significance when compared to controls. Of interest was the finding that stride length was linearly proportional to cadence ($p = 0.04$).

Patients with no hemiplegia or bilateral symptoms had parameters which were similar to control subjects. The two patients with bilateral symptoms had relatively normal gait on clinical inspection.

Patients with stroke tended to spend more time in double limb support than controls when measured in real time, presumably because this was a more stable arrangement. However, as a percentage of gait cycle, both patients and controls spent roughly an equivalent amount of time in double limb support (**Table 2**).

The unilateral measurements (**Table 3**) were assessed only for the patients who had a documented history of hemiplegia at the time of their stroke ($n = 48$). Data from control patients' right and left legs were compared and showed no significant differences, hence all unilateral data were pooled in this group ($n = 48$). As a group, the patients with a history of hemiplegia had a typical gait pattern (**Figure 1**). Their affected limbs spent more time in swing phase, significantly more time in stance phase ($p = 0.03$), and approximately an equivalent time in single limb support when compared to controls. However, when calculated as a percentage of gait cycle, which was longer in the patients with stroke, these patients spent a relatively similar amount of time in swing and stance phases and less time in single limb support on the affected side compared to controls (**Table 3**).

Patients' unaffected limbs spent significantly more time in stance phase ($p = 0.01$) and single limb support ($p = 0.04$) and approximately an equivalent time in swing phase compared to controls. As a percentage of gait cycle, patients spent relatively less time in swing phase, more time in stance phase, and an equivalent time in single limb support on their unaffected side compared to controls (**Table 3**).

Patients' affected side, compared to the unaffected side, showed that they spent less time in single limb support and stance and more time in swing with their affected side. Conversely, they spent more time in stance and less time in swing on their more stable unaffected side. This pattern was evident in the majority of patients; only three spent more time on the leg of the affected side. These three patients, who were 3 to 4 years post onset, all reported no weakness in either leg, although two of them showed mild weakness (graded 4 out of 5) of the leg of the affected side on physical examination.

Footprint patterns illustrated that the patients typically had a normal but elongated footprint on the unaffected side due to the increased time spent on this limb. A flatfoot pattern was typically noted on the affected side in

Table 2.
Gait parameters of patients with stroke and control subjects.

	All Patients	Hemiplegic Patients	No Symptoms	Bilateral Symptoms	Control
Velocity (m/min)	48.3 ± 22.7*	44.0 ± 22.9*	68.5 ± 6.7	58.6 ± 10.8	64.0 ± 10.4
Cadence (stps/min)	88.3 ± 21.5	84.8 ± 22.4*	102.8 ± 5.0	104.5 ± 7.1	95.0 ± 12.5
Stride length (m)	1.1 ± 0.6	1.1 ± 0.6	1.3 ± 0.1	1.1 ± 0.1	1.3 ± 0.5
Gait cycle/sec	1.5 ± 0.6	1.6 ± 0.7*	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.3
Double support:					
% gait cycle	—	37.4 ± 10.9	—	—	35.1 ± 6.2
seconds	—	0.62 ± 0.46	—	—	0.43 ± 0.09

*p < 0.05; mean ± 1 SD.

Table 3.
Unilateral gait parameters, as percentage of gait cycle.

	Hemiplegic Patients with Stroke		
Parameter	Affected side:	Unaffected side:	Control R and L:
SLS (%GC)	29.2 ± 8.6	33.0 ± 6.6	32.4 ± 3.4
(sec)	0.43 ± 0.19	0.51 ± 0.23	0.40 ± 0.12
Swing (%GC)	33.0 ± 6.6	29.2 ± 8.6	32.4 ± 3.7
(sec)	0.51 ± 0.23	0.43 ± 0.19	0.40 ± 0.12
Stance (%GC)	67.0 ± 6.6	70.8 ± 8.6	67.6 ± 3.7
(sec)	1.06 ± 0.50	1.14 ± 0.60	0.83 ± 0.20

Mean ± 1 SD; SLS = single limb support; GC = gait cycle.

which the heel and metatarsal regions made contact with the ground at a similar time. Furthermore, they had decreased toe contact on the affected side, and a pattern in which the great toe struck the ground first was observed in one case. Variability of footprints was noted, particularly on the patients' affected side, and a variability of subsequent stance and swing phases was also frequently observed due to small variations in the duration patients spent on the affected and unaffected legs.

The analysis of patient data with respect to time from stroke for each patient, revealed that parameters improved with increasing time post onset. This indicated that there was improvement in all parameters over time, with the largest changes occurring in the first 3 months for velocity and in the first 12 months for the other parameters. **Figure 2** illustrates the increase of cadence with time. This increase was inversely proportional to the duration of the gait cycle which decreased with time. Stride length and velocity also improved with time and were proportional to each other.

In contrast, double limb support and single limb support, stance and swing as a percentage of gait cycle for both affected and unaffected sides did not change appreciably over time (**Figures 3** and **4**). The general pattern in which patients spent more time weightbearing on the unaffected side and more time in swing with the affected side was consistent.

As a test of reproducibility, seven patients walked a total of 16 times in sequence. Unilateral parameters changed an average of 7.4 percent, comprehensive parameters changed an average of 20.7 percent. The relatively large changes of comprehensive parameters were observed to be due to patient variability in subsequent swing and stance phases as determined by inspection of the footprint patterns, and not due to measurement inaccuracy.

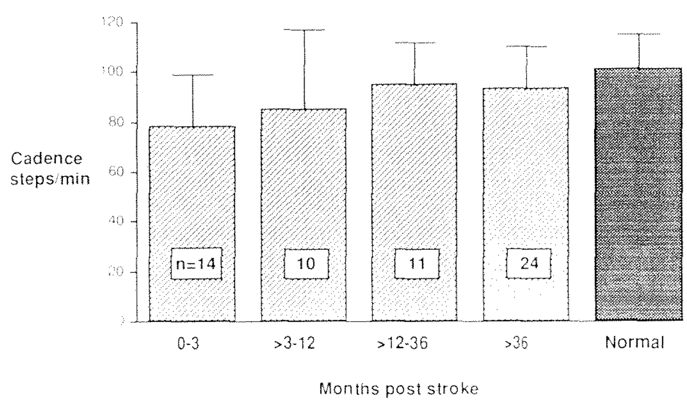

Figure 2.
Temporal changes of cadence with time since stroke. Error bars represent standard deviation.

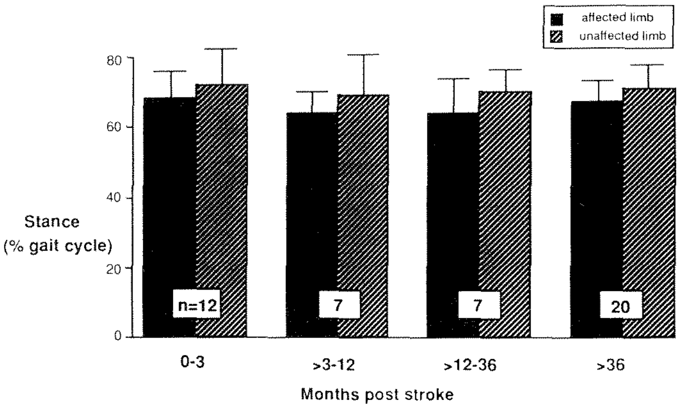

Figure 3.
Stance phase of gait vs. time since stroke. Patients spent less time on the affected leg and more time on the unaffected leg. This abnormal pattern remained constant with time. Error bars represent standard deviation.

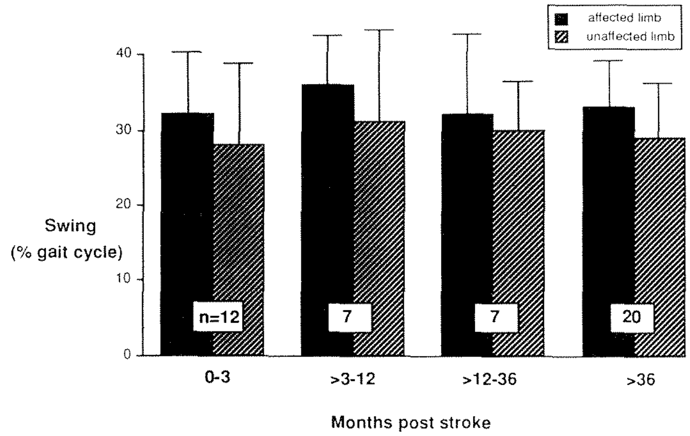

Figure 4.
Swing phase of gait vs. time since stroke. Patients' affected legs spent more time in swing, whereas the unaffected legs spent less time in swing. This abnormal pattern remained constant with time. Error bars represent standard deviation.

It is important to note that the age-matched control patients analyzed in this study had abnormal gait parameters. When compared to 500 nondisabled subjects, our control patients walked slightly slower and with decreased stride length (both 82 percent of normal), and decreased single stance (78 percent of normal). Their cadence (95 percent of normal), and gait cycle (108 percent of normal) were within the normal range.

DISCUSSION

Compared to age-matched control patients and nondisabled subjects, patients with stroke have decreased walking velocity, cadence, and stride length, and an increased gait cycle. These results are in agreement with the observations of others (8,13,14) and variations in the magnitude of these parameters are due to the wide variability of gait after stroke (1,4,6,15) as reflected by the high standard deviations of the gait parameters. Variability may also be due to the relative higher function of subjects in our group, the longer time period since stroke, and complete recovery in many of our patients. Decreased velocity, cadence and stride length are a compensation for poorer motor control (8).

The age-matched control patients in our study showed gait parameters which deviated from normal despite normal physical examinations, normal motor power, normal balance, and symmetrical gait. These deviations were likely due to the advanced age of this group: only four patients were under the age of 60, but any effects of their vascular pathology cannot be strictly ruled out. Although the use of this control group results in decreased significance of the abnormalities seen in our patients with stroke, we feel these two age-matched groups provide a more realistic comparison and provide results of greater clinical significance.

Asymmetry, which has also been correlated with motor recovery (7), was one of the most obvious features of the abnormal gait of patients with stroke. A lack of smoothness in forward progression, inequality in subsequent stance phases, swing phases, and step lengths were also observed. The variability of all these parameters was likely due to balance deficiencies and difficulty in moving the body over an unstable limb. More time was spent in stance on the unaffected side than on the paretic side. During the relatively briefer amount of time the patients' weight was over the paretic limb, the unaffected limb was quickly advanced to the next floor contact resulting in a shorter swing phase for the unaffected limb. Conversely, with an increased stance on the unaffected limb, the paretic limb spent more time in swing. Of importance was our observation that the relative duration of swing and stance phases with affected and unaffected limbs remained constant after stroke, despite improvement of other parameters. Compared to controls, patients with stroke had a longer single stance with both affected and unaffected legs independently as well as during double limb support.

General gait patterns which have been observed in patients with stroke include: a toe-first or entire sole down during stance and toe drag or inversion of the foot during swing (5,16). Foot drag may trigger pressure mats or foot switches and must therefore be distinguished from support time (5). For this reason, footprint patterns must be examined: this led to the rejection of two patients in our study who made significant floor contact by dragging their feet, giving inaccurate gait parameters. The toe-first pattern was seen in only one stroke patient in our study; most patients walked with a relatively flat foot on the affected side, but with decreased toe contact. It is likely that other patterns were not seen due to the high function of the outpatients tested in this study. Nevertheless, of significant note was that the gait analyzer clearly showed minor abnormalities which were not noted by clinical observation of the patients during their test walk. This may be of diagnostic significance and may be useful for following rehabilitation.

Walking speed has been observed to improve over the first 3 months after a stroke (12) with minimal consistent improvement or constant disability thereafter (17). It has also been reported that the longer a patient took to start walking, the less he or she was able to regain normal gait performance (12). Conversely, better early function has been correlated to further improvement or maintaining gait performance at one year (11) with recovery proportional to stroke severity, not age or sex (18). Nevertheless, despite these observations, patients may also worsen over time (11) due to changes in the paretic limb and underlying medical conditions. Velocity, the product of stride length and cadence, improved over time due to a proportional improvement of both stride length and cadence which were linearly correlated to each other. Despite the considerable improvement of these three general parameters as well as the duration of the gait cycle, the typical gait pattern with the affected side spending more time in swing and the contralateral side spending more time in stance, remained consistent and did not improve over time. This observation may indicate that patients compensate for their abnormal pattern with improved confidence, training or balance; thus resulting in improvement of the general parameters such as velocity, cadence, and stride length which are less dependent on gait pattern. We propose that recognition of this constant pattern may be useful in assessing the effects of therapeutic modalities following stroke. With the knowledge of a constant ratio of the swing and stance phases of the affected to unaffected sides, observation of an improvement of this ratio may be of major significance.

Of all patients assessed, only three spent more time on their affected side. These patients did not perceive a unilateral weakness, although weakness was noted on physical examination in two of them. This is unlikely to be due to an overcompensation for their weakness, but rather an inability of the weak leg to perform at normal velocity and stride length. Although the other patients in this study did not have demonstrable weakness of their unaffected side, it must be kept in mind that stroke may affect both sides, and the relatively stronger side may compensate for the contralateral more affected side.

Variations of gait, particularly with respect to asymmetry, suggest that it is not possible to design a single gait reeducation program for all patients and that unique deficiencies of each patient must therefore be addressed (6). For this reason, gait analysis is indicated to determine deficiencies, guide therapy, and monitor progress. Gait laboratories yield information which is comprehensive, but often difficult to correlate clinically, hence decreasing their practical application. As a consequence, ambulation is often clinically assessed as: absent, abnormal with or without assistance, or normal. The gait analysis system used in this study proved to be simple to operate and interpret, and capable of detecting small changes with time. We propose that it is an ideal screening method for gait abnormalities and useful for following patient progress. The wide range of parameters within our control group may be due to the fact that they were not entirely normal, and included patients with TIAs and asymptomatic carotid stenosis. It is interesting to speculate that quantitative gait analysis may be more sensitive in detecting subtle abnormalities which cannot be seen on computed tomography, physical, or neurological examinations. This potential sensitivity of gait analysis is of importance and requires further exploration.

This study represents the first application of a simplified gait analysis system to quantify gait parameters and the temporal changes following stroke in a large number of patients. Gait analysis in general can be of significant importance in determining and following the results of surgical and other therapeutic modalities for the documentation, correction, and improvement of abnormal gait patterns. Ambulation is of obvious importance in the physical and mental state of the stroke patient and we propose that the application of simplified gait analysis as a tool for assessing patients with stroke will aid in diagnosing and following gait aberrations and the effects of therapeutic modalities.

CONCLUSIONS

The gait analyzer provided relevant statistical data, and allows for simple follow-up post-stroke. It was reliable and easy to use and inexpensive compared to a gait laboratory. The gait of patients with stroke was characterized by decreased velocity and cadence, and increased gait cycle and double limb support. Their affected limbs spent more time in swing and stance, and their unaffected limbs spent more time in stance and single limb support compared to controls. The patients' hemiplegic side, when compared with their contralateral side, spent less time in stance and more time in swing. A flatfoot pattern was typically noted on the affected side. General gait parameters improved over time, with the largest changes occurring in the first 12 months; however, parameters which describe the asymmetrical pattern of gait did not change over time. These included the percentage of time spent in double and single limb support, stance, and swing. The abnormal gait was probably due to difficulty in moving the body over an unstable limb. The ability of the device to demonstrate abnormalities which were not evident on clinical evaluation is a potentially important observation.

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