The Value of a Continuous Ambulatory Activity Monitor to Quantify the Amount and Intensity of Daily Activity in Patients with Rheumatoid Arthritis

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ABSTRACT. ***Objective.*** To examine the reliability, validity, and responsiveness of a continuous ambulatory activity monitor in patients with rheumatoid arthritis (RA).

Methods. Forty-one patients with RA, participating in a randomized controlled trial examining the effect of an intensive exercise program, were assessed by means of the Dynaport® ADL (activities of daily living) monitor® (AM). The time spent on activities (locomotion, standing, and active sitting) during 24 hours and the intensity of trunk movement during these activities were recorded. To determine test-retest reliability 20 patients were reassessed with the AM one week after the first assessment. Construct validity of the AM was determined by comparing the AM results with physical fitness measures (muscle strength, endurance, joint mobility), disease activity, and functional status. As well, 37 patients were assessed 18 months after the first assessment to determine responsiveness.

Results. All AM measurements showed satisfactory test-retest reliability (ICC 0.63–0.76). AM measures were significantly associated with physical fitness, functional status, and disease activity, indicating construct validity of the AM. The AM could discriminate between patients with improvement and deterioration in physical fitness, indicating sufficient responsiveness of AM variables.

Conclusion. This study shows the value of an ambulatory activity monitor to quantify both the amount and intensity of physical activity of patients with RA during a day in their own environment. The ambulatory activity monitor seems to be a promising instrument for research into rehabilitation of patients with RA. (J Rheumatol 2001;28:745–750)

Key Indexing Terms:

ACTIVITIES OF DAILY LIVING | RHEUMATOID ARTHRITIS | EXERCISE THERAPY
AMBULATORY MONITORING | MOTOR ACTIVITY | PHYSICAL FITNESS

There is convincing evidence that in patients with rheumatoid arthritis (RA) intensive dynamic exercise therapy has a positive effect on physical capacity (aerobic capacity, muscle strength, joint mobility) and has — at least in the short term — no detrimental effects on disease activity[1]. However, in a number of clinical trials exploring the effect of exercise therapy in RA, an increase in physical capacity did not run parallel with an improvement in the performance of activities of daily living (ADL)[2-5]. The instruments for measuring function used in most exercise trials only refer to the level of difficulty of a limited number of predefined activities. Instruments measuring the total amount and intensity of all spontaneous activities performed throughout the day may be more valid and more sensitive to detect clinical changes in ADL-function.

Portable activity monitors are now available that can discriminate between different activities like sitting, standing, and walking and can quantify movement intensity during these activities[6-9]. Ambulatory activity monitoring proved to be of value in a number of disorders, e.g., low back pain[10], congenital heart diseases[11], and claudication intermittens[12].

The practical application and validity of ambulatory activity monitoring in patients with RA and osteoarthritis was described by Walker, *et al*[13-16]. The activity monitor (AM) used by these authors estimated the energy spent by the patient in 24 hours. Significant correlations of this variable with functional ability and radiological damage were found in patients with RA[16]. In comparison with functional ability as measured by the Health Assessment Questionnaire (HAQ), the "energy spent" measure appeared to be more sensitive to change. The value of an AM with the ability to

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quantify both intensity of activities (energy) and amount of activities (time spent sitting, standing, and walking) as an outcome measure in rheumatology rehabilitation clinical trials needs to be established. We examined the value of such an AM as an outcome measure in rehabilitation research involving patients with RA in terms of test-retest reliability, construct validity, concurrent validity, and responsiveness.

MATERIALS AND METHODS

Patients. This study was conducted as part of the randomized RAPIT trial (RA Patients in Training), in which the effect of a longterm, intensive weight-bearing exercise program for patients with RA was investigated. One group of patients was randomly allocated to follow an intensive training program twice a week for 2 years, whereas the other group was to be treated by a physical therapist on doctor's prescription (usual care) only. In total, 300 patients with RA according to the 1987 revised American Rheumatology Association criteria[17] were included by June 1997. In the framework of the RAPIT trial, patients were assessed every 3 months over a period of 2 years. These assessments comprised measures of functional ability, physical capacity (muscle strength, endurance, and range of motion), disease activity, and quality of life (QOL). The RAPIT trial was approved by the medical ethics committees of all participating hospitals and all patients gave written informed consent.

To validate the continuous ambulatory activity monitor, 66 consecutive participants of the RAPIT trial recruited at the Leiden University Medical Center were asked to participate; 49 patients gave written informed consent for the AM study. The AM study was approved by the medical ethics committee of the Leiden University Medical Center. All measurements in Leiden were done by 2 research exercise therapists (BO and IP).

Study design. In all 49 patients, the additional assessments of physical activity were performed at baseline of the RAPIT study (t_1) and at 18 months later (t_2). Twenty-four patients wore the AM one week precisely after t_1, on the same day of the week, to examine test-retest reliability.

Measures. Basic characteristics (sex, age, disease duration, employment status) of all patients were obtained by interview and from the medical record.

Physical activity over 24 h was assessed by means of the Dynaport® ADL monitor® (McRoberts BV, The Hague, Netherlands), a lightweight AM that is worn around the waist. It records the signals of 3 unidimensional acceleration sensors[7]. Two of the sensors are placed in the recorder and an external sensor is placed in an elastic strap and is worn on the left upper leg. It takes about 10 min to apply the AM. The signals of the 3 sensors can be recorded during at least 24 h. The recorded signals are afterwards imported into a desktop computer for further processing. Special software is available to analyze the signals[18], resulting in 42 variables. Importing, processing, and analysis of data takes about 30 min. Each 24 h assessment requires 10 to 20 MB hard disk space. We describe the results of 7 physical activity measures: the percentage of time spent on locomotion (LoT), standing (StT), and active sitting (aSiT) during 24 h; the mean intensity of trunk movement during locomotion (LoTMI), standing (StTMI), and sitting (SiTMI); and the mean intensity of trunk movement during locomotion, standing, or sitting (TMI). Movement intensity is calculated as the vector of accelerations of the trunk at the body mass center in longitudinal and frontal direction, and is expressed in m/s^2. Active sitting was defined as sitting in combination with trunk movements with a movement intensity above noise level. The Dynaport® ADL monitor® has been described in detail[19,20].

In addition, physical activity was measured with the Baecke Questionnaire. The total Baecke score is a summation of 3 subsections (work activity, sports activity, and non-sports leisure activity) and ranges from 0 (not active at all) to 15 (very active). The questionnaire proved to be reliable (test-retest correlation 0.77 to 0.93)[21,22] and valid in healthy populations[23-25].

Disease activity was measured by the Disease Activity Score based on 4 variables (DAS4)[26]: the Ritchie Articular Index (RAI), 44 swollen joint count, erythrocyte sedimentation rate (ESR), and a visual analog scale (VAS) for general health. The DAS4 was calculated according to the following formula:

$$\text{DAS4} = [0.54 \times \sqrt{(\text{RAI})} + 0.065 \times (\text{swollen joint count}) + 0.33 \times \text{Ln}[\text{ESR}] + 0.007 \times \text{VAS patient global assessment of disease activity}]$$

Joint mobility was assessed using the Escola Paulista de Medicina range of motion (EPM-ROM) scale, a measure for general flexibility derived from 10 selected joint motions[27]. The scale ranges from 0, full flexibility, to 30, indicating severe limited joint flexibility.

Physical fitness was determined by measuring quadriceps muscle strength and endurance. Quadriceps muscle strength was measured with an isokinetic dynamometer (Enknee, Enraf Nonius, Delft, The Netherlands). The highest peak torque of 3 attempts at 60°/s angle velocity of the left and right knee was averaged. Endurance was measured by a short bicycle ergometer test based on tests described by Wallin and Brudin[28]. In the bicycle test the patients had to cycle as long as possible with a cycle frequency of at least 50 rounds per minute. After 1 minute stationary cycling at 20 watt the resistance was raised by 10 watt every 30 s. The total duration of cycling was used as an estimator of aerobic capacity.

Change in physical fitness between t_1 and t_2 as perceived by the patient was measured with a VAS ranging from –100 (strong decline in physical fitness) to 100 (strong increase in physical fitness).

Functional status was measured with (a) the HAQ[29,30], (b) a 50 foot walk test (time needed to walk a distance of 50 feet), and (c) the physical functioning component of the Rand 36 item Health Survey 1.0 (Rand). The Rand survey includes the same items as the Medical Outcome Survey Short-form 36, and although the scoring procedures are somewhat different, the effects on the final scores are minimal[31].

Analysis. Test-retest reliability was determined by calculating the intraclass correlation coefficient (ICC 2.1) of the results of 2 AM assessments one week apart[32].

Both construct validity and concurrent validity were determined. Construct validity reflects the ability of an instrument to measure an abstract concept or construct, while concurrent validity examines the value of a new measure in comparison with established methods[33].

Construct validity was determined by studying the association between the AM measurements and measures representing the following dimensions: disease activity, joint mobility, physical fitness, and functional status. The DAS4 and EPM-ROM represent the disease activity dimension and joint mobility dimension, respectively. Measures representing the dimensions of physical fitness and functional status were derived by factor analysis. The physical fitness dimension was defined by the first principal component of muscle strength and endurance, and the functional status dimension by the first principal component of the 50 foot walk test, HAQ, and the physical functioning component of the Rand. Association between the AM (all 7 measurements together) and each of the 4 dimensions was determined by testing the R-square of the 7 measurements with each domain in a multiple regression model. After this, the association between each AM measurement and each domain was quantified using Spearman's correlation coefficient.

To determine concurrent validity the Spearman correlation coefficients of the AM measurements with disease activity, joint mobility, physical fitness, and functional status were compared with associations of alternative measures (HAQ, Rand, and Baecke Questionnaire for physical activity) with the same parameters. Differences between correlation coefficients were tested for statistical significance by Hotelling's t test.

To determine responsiveness of the AM measurements in comparison with alternative measures, patients with the largest improvement between t_1 and t_2 (responders) and patients with the largest deterioration (nonresponders) in physical fitness were selected. Responders were defined as patients with improvement on the VAS for change in physical fitness (VAS > 0)

combined with an increase in muscle strength and endurance (change scores > 0). Nonresponders were patients with no improvement on the VAS (VAS < 0) in combination with decreased muscle strength and endurance (change scores < 0). Because of the small sample size of the nonresponders, we also included in this group patients with more than 10% deterioration on at least 2 of the 3 above mentioned variables. Effect sizes were calculated as the difference in changes from baseline between the responders and nonresponders divided by the pooled standard deviation of the change scores of the 2 groups[34]. Differences in effect sizes between AM measurements and concurrent measures were tested according to the method described by Buchbinder, *et al*[35]. The ability of the AM to discriminate between responders and nonresponders was examined by means of the area under the receiver operating characteristic (ROC) curve.

RESULTS

First assessment. The measurements of 41 out of 49 patients were suitable for analysis. Dropout was caused by a technical defect of one of the activity monitor devices in all cases. Nineteen of the 41 patients had been allocated to the intensive weight-bearing exercise program group and 22 to the usual care group. There were no significant differences between analyzed and non-analyzed patients with respect to age, disease duration, and functional status (HAQ) (data not shown). Basic sociodemographic, clinical, and disease characteristics of 41 patients are shown in Table 1. The AM results in these patients are presented in Table 2. In 24 hours, patients spent 27.2% of their time on locomotion, standing, or active sitting. The rest of the time was spent on passive sitting and lying. There was no difference in physical activity measures between men and women ($p > 0.05$, Mann-Whitney U test). Employed participants had a significantly higher percentage of time spent on locomotion in comparison with participants who were not employed ($p < 0.05$, Mann-Whitney U test).

Test-retest reliability. In 20 patients there were 2 physical activity measurements suitable to examine reliability. The values of the first and second physical activity assessments and the ICC of the 2 assessments are shown in Table 3. Figure 1 illustrates the data of "time spent to locomotion," according to Bland and Altman[36]. Except for trunk movement intensity during standing and mean trunk movement intensity, there were no statistically significant differences between the first and second assessments.

Construct validity. Correlations between AM measurements and disease activity, joint mobility, physical fitness, and functional status dimensions are presented in the upper part of Table 4. Measurements with higher scores for a worse situation (HAQ, DAS4, EPM-ROM, and RAQOL) were first multiplied by –1; thus all positive correlations represent positive associations. Overall testing (multiple R) revealed that both physical fitness and functional status were significantly related to the 7 measures of the AM. Five of 7 AM measures were significantly associated with physical fitness. Moreover, trunk movement intensity during locomotion and mean trunk movement intensity were also significantly associated with disease activity, joint mobility, and functional status.

Table 1. Basic characteristics of 41 patients with RA participating in an exercise trial.

	Median (range)
Age, yrs	55 (35–69)
Disease duration, yrs	6 (1–26)
Males/females, n	13/28
Employed, yes/no	17/24
Disease activity	
Disease Activity Score, DAS4	3.9 (1.2–6.8)
Joint mobility	
EPM-ROM, 0–30	6.0 (2.0–9.5)
Physical fitness	
Bicycle endurance test, min	5.4 (2.4–11.3)
Quadriceps muscle strength, N	79.0 (15.0–184.5)
Physical activity	
Baecke Questionnaire, 0–15	7.5 (5.5–9.6)
Functional status	
15 ft walk test, s	11.8 (8.5–20.5)
HAQ, 0–3	0.63 (0–2.25)
Rand-36 physical functioning, 0–100	60.0 (20.0–90.0)

Table 2. Physical activity measurements of the AM in 41 patients with RA.

	Mean (SD)
Time spent, % of 24 h	
Locomotion	5.9 (2.5)
Standing	19.3 (6.8)
Sitting	32.5 (9.5)
Active sitting	2.0 (1.1)
Nonactive sitting	30.5 (9.1)
Lying	42.1 (8.8)
Movement intensity, m/s^2	
Locomotion	1.90 (0.35)
Standing	0.43 (0.07)
Sitting	0.22 (0.06)
Mean trunk movement intensity	0.85 (0.13)

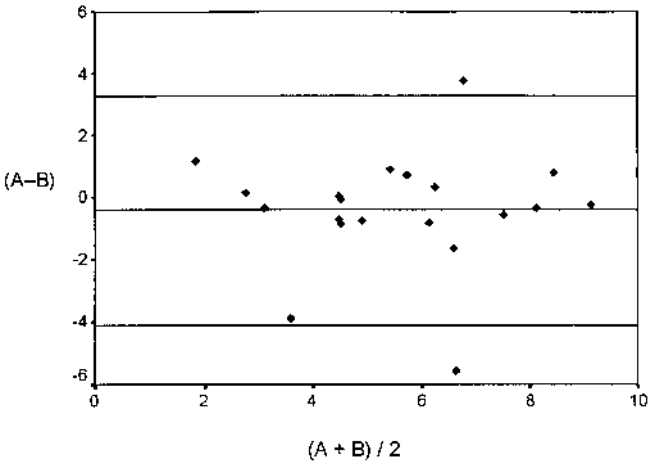

Figure 1. Plot of the difference between first (A) and second (B) AM assessments against the mean of the first and second assessments in 20 patients with RA. Figure illustrates data for the AM variable "time spent on locomotion" as percentage of 24 hours (ICC 0.63).

Table 3. Test-retest reliability of physical activity variables measured by the AM (n = 20).

	First Assessment, mean (SD)	Second Assessment, mean (SD)	Mean Difference (SD)	ICC (2,1)
Time spent, % of 24 h				
Locomotion	5.4 (2.2)	5.7 (2.2)	0.4 (1.9)	0.63
Standing	20.4 (7.7)	18.4 (8.1)	–2.0 (5.9)	0.72
Active sitting	2.1 (1.4)	2.7 (2.2)	0.6 (1.3)	0.76
Movement intensity, m/s^2				
Locomotion	1.83 (0.29)	1.94 (0.42)	0.11 (0.28)	0.69
Standing	0.43 (0.07)	0.47 (0.08)*	0.04 (0.05)	0.75
Sitting	0.22 (0.07)	0.24 (0.07)	0.02 (0.05)	0.71
Mean trunk movement intensity	0.83 (0.11)	0.89 (0.15)*	0.06 (0.09)	0.72

*Second assessment > first assessment ($p < 0.05$, paired t test).

Table 4. Associations (Spearman rho) of AM variables, HAQ, physical functioning component of the Rand, and the Baecke physical activity questionnaire with the dimensions "disease activity," "joint mobility," "physical fitness," and "functional status" in 41 patients with RA.

	Disease Activity[1]	Joint Mobility[2]	Physical Fitness[3]	Functional Status[4]
AM overall, multiple R	0.43	0.54*	0.68***	0.61**
AM, time spent, % of 24 h				
Locomotion	0.00	0.03	0.48**	–0.07
Standing	–0.16	–0.05	–0.18	0.01
Active sitting	0.11	0.09	0.30*	–0.03
AM, movement intensity, m/s^2				
Locomotion	0.28	0.45***	0.39**	0.60***
Standing	0.34**	0.02	0.32**	0.16
Sitting	0.15	0.09	0.23	–0.03
Mean trunk movement intensity	0.32**	0.42***	0.41***	0.53***
Other measures of function				
HAQ‡	0.49***	0.52***	0.19	—
Rand, physical functioning‡	0.10	0.17	0.38**	—
Baecke questionnaire	0.16	0.04	0.09	0.09

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$ (2 tailed).
‡Correlations of the HAQ and Rand with the functional status dimension are not presented because this dimension is based on the HAQ and Rand.
[1]Disease activity as measured by DAS4. [2]Joint mobility as measured by EPM-ROM. [3]First principal component of endurance and muscle strength. [4]First principal component of 50 foot walk test, HAQ, and Rand-36 (physical function).

Concurrent validity. Correlation coefficients of other measures of (dis)ability with the aforementioned 4 dimensions are presented in the second part of Table 4. The HAQ was significantly associated with disease activity and joint mobility, but not with physical fitness. The physical function component of the Rand was not significantly related with disease activity and joint mobility, but was with physical fitness. The Baecke Questionnaire for physical activity was not associated with any other variable.

Responsiveness. After 18 months 37 out of 41 patients were assessed with the AM again. Two patients could not be reassessed because of severe comorbidity and 2 others were unwilling to participate in the second part of the study. The average scores of the AM measurements did not change significantly between baseline and 18 months (n = 37). Nine responders (6 treatment group, 3 usual care group) and 8 nonresponders (8 usual care group) were selected. Data for the effect size and area under the ROC curve are presented in Table 5. Most effect sizes of AM measurements were higher in comparison with the effect sizes of the HAQ and Rand; however, these differences did not reach statistical significance.

DISCUSSION

This study shows the value of an ambulatory AM with the ability to quantify both the total amount and intensity of

Table 5. Responsiveness of AM variables, HAQ, and Rand (physical functioning component) in 9 responders and 8 nonresponders.

	Effect Size	Area Under ROC Curve
Time spent, % of 24 h		
Locomotion	0.04	0.53
Standing	0.71	0.72
Active sitting	1.09*	0.78**
Movement intensity, m/s^2		
Locomotion	0.26	0.56
Standing	0.64	0.71
Sitting	0.56	0.61
Mean trunk movement intensity	0.57	0.68
Functional status measures		
HAQ	0.26	0.57
Rand-36, physical functioning	0.44	0.57

Effect size: (change-score responders – change-score nonresponders)/pooled SD of the change scores of both groups. *p < 0.05 (t statistic); **p < 0.05 (asymptomatic significance, null hypothesis: true area = 0.5).

several physical activities of patients with RA during a day in their own environment as an outcome measure in rehabilitation research. AM measurements were significantly associated with physical fitness and functional status and could discriminate between patients with improvement and deterioration in physical fitness.

This is the first report concerning continuous ambulatory monitoring of both total amount and intensity of daily activity in patients with RA. Moreover, associations between AM measures and several parameters representing various dimensions of consequences of RA were studied. Apart from the ambulatory monitoring method there are other means to quantify the amount and intensity of spontaneous activity, such as video observations and patient diaries[37]. However, the AM has 3 important advantages above the other methods: the AM quantifies aspects of physical activity in the patients' own environment, the AM results are not influenced by the subject's opinion, and the AM is, without cross cultural validation, usable in different cultures and different patient groups.

Considering the expected normal day-to-day variance in physical activity, all AM measurements showed satisfactory test-retest reliability in this study. Repeatability of AM measurements can possibly be further enhanced by measuring more days instead of one period of 24 hours[38]. For that purpose, it is desirable to enhance the comfort of wearing the AM by producing a smaller and lighter recorder.

Adequate construct validity of the AM is indicated by the positive associations between the AM measures and several dimensions of the consequences of RA. Both the "time spent on" and the "movement intensity" measurements obtained with the AM were significantly associated with physical fitness. Further, the associations of most AM measures with the physical fitness dimension were stronger in comparison with the associations between other measures of functional status (HAQ, Rand, Baecke) and physical fitness. Although the differences between these associations did not reach statistical significance, the results suggest that the AM reflects the physical fitness dimension of daily function more accurately than other measures presently in use in rehabilitation research. The associations of the movement intensity measurements with functional status are comparable with the association between the "energy spent" variable and the HAQ found by Walker, *et al*[16]. In contrast to Walker, *et al*, our results also show significant associations between AM measures and disease activity.

It is remarkable that in our study the "time spent on" measures of the AM were less strongly associated with disease consequences in comparison with the "intensity" measures. It is conceivable that patients with RA are more likely to change the intensity of their activities rather than to adapt their daily schedule as a consequence of their disease.

There was no association between the Baecke activity questionnaire and any of the other variables. The Baecke Questionnaire is not disease-specific, but is developed for healthy people. This may be a possible explanation of the low association. In other studies, associations between questionnaires and activity monitors were also found to be low[39]. Apparently the Baecke Questionnaire is not an alternative measurement tool to quantify physical activity in patients with RA.

The responsiveness of the AM measurements in this study seems to be higher than the responsiveness of the HAQ and Rand. However, the responsiveness is based on a small number of improved patients in comparison with deteriorated patients and most values did not reach statistical significance. Despite these limitations, the results concerning the responsiveness of the AM are promising.

This study shows the value of an activity monitor as a measure of both the total amount and the intensity of physical activity in research into rehabilitation of patients with RA.

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