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Six-minute walk test on a special treadmill: Primary results in healthy volunteers

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Abstract

Background: *The guidelines approved by the American Thoracic Society in 2002 definitely recognize the six-minute walk test (6MWT) as a useful tool for the evaluation of physical efficiency in individuals with at least moderate chronic obstructive pulmonary disease, heart failure and intermittent dysbasia. So far, the American Thoracic Society has not approved the use of a treadmill to determine the six-minute walking distance (6MWD) because patients are unable to pace themselves on a treadmill. The purpose of our work was to prove that these problems could be avoided if physical efficiency is evaluated with the use of a modified treadmill.*

Methods: *The work evaluates the function of a treadmill able to adjust its speed to the walking speed of healthy volunteers. The evaluation is based on a comparison of the distance covered by the healthy volunteers and the comfort of the test on the treadmill during six minutes with the distance covered and comfort during the same period in a 22-metre-long hallway in 29 healthy volunteers. Non-invasive blood pressure and pulse measurements were taken immediately before and after the test.*

Results: *The average distance covered during the six-minute period on the treadmill was 57.1 m longer than in the hallway. The comfort of the treadmill test was indicated to be better by 18 subjects, worse by 4 subjects and identical by 7 subjects.*

Conclusions: *The tests confirm that the speed of the modified treadmill adjusts properly to the walking speed of the healthy volunteers. The hemodynamic effects were identical for the healthy volunteers both in the hallway and treadmill tests. The distance differences were caused by turnarounds in the corridor test. The results obtained with the special treadmill allow us to develop a new method and, at present, provide a basis for a second stage of research comprising subjects with diagnosed heart failure.* (Cardiol J 2007; 14: 447–452)

Key words: six-minute walk test, modified treadmill, healthy volunteers

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Introduction

The guidelines approved by the American Thoracic Society (ATS) in 2002 definitely recognize the six-minute walk test (6MWT) as a useful tool for the evaluation of physical efficiency in individuals with at least moderate chronic obstructive pulmonary disease, heart failure and intermittent dysbasia [1]. In order to compare the results obtained in various research centres, the guidelines recommend that the test be performed in a hallway 30 m in length and at least 3 m in width. As a result, some centres without hallways of this size have limited possibilities of carrying out this simple test.

The authors of the ATS report appreciate the advantages of the 6MWT on a treadmill as it saves space and allows constant monitoring during the exercise.

So far, ATS has not approved the use of a treadmill to determine the six-minute walking distance (6MWD) because patients are unable to pace themselves on a treadmill. The divergence between the distances covered on the treadmill and those covered in the hallway was pointed out. To support this point of view, a study of patients with severe lung disease was presented in which the mean distance walked on the treadmill was shorter by 14% when compared with the standard 6MWD using a 100-ft hallway [2]. In particular, doubts were expressed regarding the wide range of differences, with patients walking between 400 and 1,300 ft on the treadmill compared to 1,200 ft in the hallway.

The popularity of the 6MWT in clinical practice [3–8], problems with the performance of the test on the treadmill, and the differences between the 6MWT in the hallway and on the treadmill encouraged us to develop a treadmill that complies with the algorithm for safe adjustment of its speed to the walking capacity of the patient. The purpose of our work was to prove that these problems could be avoided if physical efficiency is evaluated with the use of a modified treadmill.

Methods

The common treadmill forces patients to adjust their walking speed to its belt speed in order to prevent them from being thrown from the belt. The new treadmill should change its belt speed when the patient's walking speed changes and change it quickly enough to keep the patient on the treadmill. Initially, the preparation of such a treadmill seemed to us difficult and another solution was chosen. We decided to link the speed of the belt with the patient's position on the surface of the treadmill [9]. When the patient is close to the front of the treadmill, the maximum speed of the belt is achieved, when they are close to the end of treadmill, the belt stops. By increasing the walking speed, the patient moves toward the front of treadmill, and the belt speed increases; when the patient slows, the belt moves them backward, and the speed of the belt is adjusted again. In order to realize such an algorithm, precise measurements of the patient's position on the treadmill were necessary. Due to the inconvenience of other methods, the decision was made to measure the patient's position wirelessly.

First, the ultrasound wave reflected from the patient on the treadmill was chosen to measure the distance from this patient to the front of the treadmill. Due to extraneous echoes from surrounding objects, measurements were uncertain and the method proved to be inconvenient. Because transmitting and receiving ultrasonic waves is simple and cheap, we decided to continue using ultrasound after a little modification. In our new method (patent protected), the patient carried a transmitter which simultaneously produced short impulses of ultrasound and infrared (about 100 ms duration). A receiver at the front of the treadmill received both signals, and the distance between the transmitter and receiver was calculated from the time delay between the two received signals. The distance measurements turned out to be accurate (error less than 10 mm), and due to the shorter direct ultrasound signal, extraneous echoes did not interfere with the measurements. Figure 1 shows the principle of patient position measurement using the mixed ultrasound/infrared method. Carrying a transmitter seemed slightly

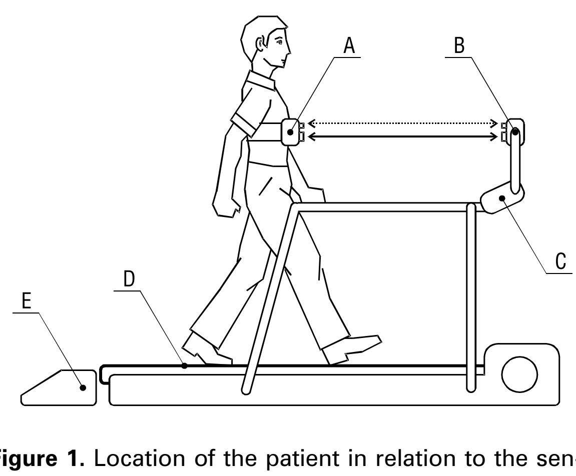

Figure 1. Location of the patient in relation to the sensors controlling the patient's position on the treadmill: A, B — transmitter and receiver of the ultrasound wave and infrared radiation; C — control panel; D — treadmill belt; E — a step preventing the patient from falling off the treadmill.

uncomfortable for the patients but safe, because only the person carrying the transmitter could operate the treadmill. Additionally, the infrared beam could be used to transmit the patient's heart rate to a display at the front of the treadmill.

When the position measurement system with the transmitter and receiver was ready, preparation of the speed control for the treadmill began. We adapted an ERT-100 treadmill produced by ITAM, by connecting the receiver and installing a new control program to its console. Using the "6-minute walk test program" in the control panel, the operator could input the maximum speed of the treadmill belt and start the test. The program terminated the test after six minutes and displayed the distance covered by the patient. The treadmill belt achieved its maximum speed when the distance between the receiver and the transmitter was less than 30 cm and stopped when the distance exceeded 120 cm. Between those two distances, the speed changed proportionally from 0 to the maximal value which could not exceed 10 km/h.

The modified treadmill was than equipped with an algorithm adjusting its speed to the walking speed of the patient. As mentioned before, the speed was controlled by constant measurement of the patient's position on the treadmill. The relevant diagrams are presented in Figures 1 and 2.

The population tested

Twenty-nine healthy volunteers, full-time and extramural students of the Academy of Physical Education in Katowice, took part in a test. The volunteers were 28 years old (21–48) on average.

The order of taking the 6MWT on the treadmill and in the corridor was established at random. The tests with the use of both methods were performed with an interval of 7 days.

The 6MWT in the hallway

For each individual, the 6MWT was performed along a corridor 22 m in length, according to Lepkin's protocol [10]. The participants were told to walk the distance of 22 m, back and forth, at their own speed, in such a way that they would cover the longest possible distance within 6 min. The volunteers were allowed to slow down or stop, but at the end of the test they were expected to feel that they could not walk any further within 6 min.

The 6MWT on the treadmill

For the six-minute walk test on the treadmill, software adjusting the belt speed to the patient's walking speed in the range of 1–10 km/h was applied. The treadmill was in the horizontal position.

The program terminated the test after six minutes and displayed the distance covered by the patient.

Information for the patients regarding the correct interaction with the treadmill was based on previous experience gained during work with a modified treadmill, which were published in 2005 [11]. The test on the treadmill was preceded by a training session lasting a few minutes the day before the actual test. During the training session, the participants learned how the treadmill worked and walked a distance of 100 m at a changeable pace and practiced stopping and restarting the walk.

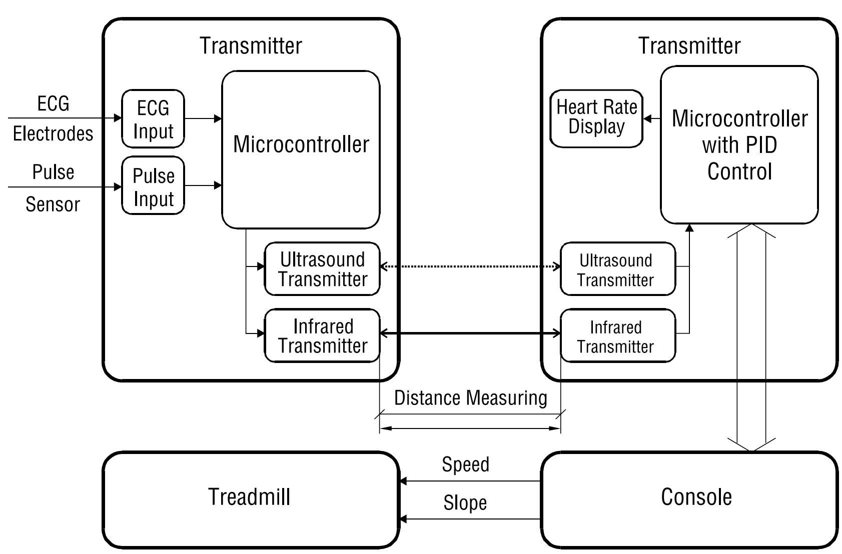

Figure 2. A diagram of the applied solution.

The participants were informed about the treadmill test in an identical way as to the corridor test.

Analysed parameters

The comfort of the test and the distance covered in metres were subject to evaluation in both cases. The evaluation scale for comfort included the question of which type of test was less problematic during performance and whether the comfort of both tests was so similar that the differences were negligible. The number of indications to a given type of test was calculated. The treadmill was also monitored from the point of view of smooth speed adjustment to an individual's sudden slowdown without affecting his or her balance.

Heart rate and blood pressure were measured before and after each test in order to assess the hemodynamic impact of both 6MWT methods.

Statistical analysis

The aim of the statistical analysis was to compare the values of the distance covered obtained using both 6MWT methods. Using the Student's test for matched pairs for independent trials, heart rate and blood pressure before and after the test were also compared.

Multidimensional statistical research was also conducted by means of the T2 test for vectors of the expected values for both methods, in order to verify whether the compared research led to similar hemodynamic consequences.

Results

The comfort of the treadmill test was indicated to be better by 18/29 of the participants, the hallway test was indicated to be better by 4/29 of the participants and both tests were evaluated as identical in terms of comfort by 7/29.

During the test, healthy volunteers were walking most frequently at a speed of 7 km/h (4–10).

The average distance covered on the treadmill was 683.0 m and was usually 57.1 m longer, on average, than in the corridor (Table 1). This difference turned out to be statistically significant.

On average, the participants covered 29 laps during the hallway test (19–36).

No considerable difference could be seen in heart rates before the tests. In addition, the resulting accelerated heart rate after both types of tests did not show any marked difference (Table 2), as did blood pressure (Table 2).

The Hotteling T2 test was used to assess the equality of vectors of the expected values for seven analyzed parameters of the 6MWT.

The obtained results, with $T2 = 11.7$ and $F = 7.3 < 53$ (where 53 stands for the threshold of the hypothesis at significance level < 0.05), gives clear evidence of the identical hemodynamic impact of both testing methods.

Discussion

The literature on the 6MWT does not provide any comparative material for our results obtained during a walk along a corridor 22 m in length performed by healthy individuals with average age 28 years. The mean distance covered by our volunteers, amounting to 625.9 m, may only be compared with data obtained by other researchers regarding the distance walked by healthy subjects over 40 years of age. In the work by Enright et al. [12], the distance was equal to an average of 535 m, while in the work by Troosters et al. [13], to 631 m. In comparison with the distance covered by the subjects in the study by Enright et al. [12], our volunteers covered almost 100 m more. The recorded difference is very likely to be related to our volunteers' young age (29, on average). In the study by Troosters et al. [13], the average distance on a 50-metre-long corridor was a few metres longer than that covered by our healthy volunteers who were two decades younger. Almost identical distances in completely different age groups could be explained by the fact that older patients had to perform half as many turnarounds in a 50-metre-long corridor.

ATS guidelines approved in 2002, which specify the length and width of the corridor, will certainly make it possible to compare the 6MWT results obtained in various centres. Another way of comparing

Table 1. The distance covered during the six-minute period walk test on the treadmill and in the hallway.

Method of performing the six-minute walk test	Mean distance [m]	SD	Difference between the means [m]	p
Hallway	625.9	94.6	57.1	< 0.009
Treadmill	683.0	65.2		

Table 2. The heart rate and blood pressure before and after the test conducted on the treadmill and in the hallway.

Method of performing the six-minute walk test	Before the test						After the test					
	Hallway		Treadmill		Difference between the means	p	Hallway		Treadmill		Difference between the means	p
	Mean value	SD	Mean value	SD			Mean value	SD	Mean value	SD		
Heart rate [bpm]	76.9	12.9	81.4	13.3	4.5	< 0.19	96.8	19.5	103.2	22.5	6.4	< 0.25
Systolic pressure [mm Hg]	125.9	13.4	123.0	12.5	–2.9	< 0.4	134.2	16.2	135.8	18.5	1.6	< 0.73
Diastolic pressure [mm Hg]	81.4	7.8	80.2	8.0	–1.2	< 0.57	83.7	11.8	82.6	9.6	–0.9	< 0.71

the results obtained in various places is the proposed return to the idea of using the treadmill.

In our study, most (i.e. 86%) of the healthy volunteers who participated in the test evaluated the comfort of the treadmill test as better than or the same as the hallway test. Hence, the applied design solutions and algorithm may be regarded as appropriate and flexible in terms of adjusting the speed of the treadmill belt to the walking speed of a healthy individual.

In the paper by Stevens et al. [2], the participants could start, speed up and slow down the treadmill by means of a special switch. Although Stevens et al. [2] enabled the participants to adjust the treadmill to their walking speed "by hand", the distance covered on the treadmill turned out to be much shorter than the distance walked in the corridor because the participants found it difficult to adjust to the speed of the treadmill belt.

We applied the use of a treadmill that adjusts its speed to the walking capacity of the individual. As a result, the persons taking part in the test covered a distance 57.1 m longer, on average, than in the corridor. The distance covered on the treadmill was longer than that walked in the hallway due to the flexible adjustment of the treadmill belt to the walking speed and due to the avoidance of multiple turnarounds, and hence the need to speed up and slow down, as in the corridor test.

Multi-aspect analysis of the results including the distance covered, blood pressure and heart rate, measured before and after the 6MWT, shows similar hemodynamic consequences for both methods. Thus, it can be inferred that in the future it will be possible to determine the conversion rate, at least for healthy subjects, facilitating the comparison of the results obtained during a test in a 100-ft hallway with the results from an adjustable treadmill.

As opposed to conditions in the corridor, the 6MWT on a moving treadmill facilitates convenient monitoring of heart rate and arterial blood pressure. This enables the hemodynamic surveillance that is necessary for safe test performance in patients with cardiac insufficiency.

The attempt by Stevens at al. [2] to use the treadmill for a 6MWT in patients with respiratory failure did not meet the expectations as it shortened the distance in comparison with the hallway test. Our results show the expected elongation of the distance compared with the hallway test, although they cannot currently be referred to patients with intermittent dysbasia, heart failure or severe lung disease. Patients suffering from such diseases are less fit, which may affect their ability to perform the

6MWT on a modified adjustable treadmill. We are aware that the decision of whether our modified treadmill meets the expectations of physicians who use the 6MWT in their medical practice and research can only be made after performing tests on these groups of patients. However, the modified treadmill, equipped with solutions that are offered by no other firm, may be already be recommended for fitness exercise because the person using the treadmill may avoid dyspnea by adjusting his or her walking speed.

Conclusions

The increased comfort of the 6MWT and the longer distance covered when using the treadmill compared with the distance covered in the hallway could indicate that the algorithm of speed adjustment of the treadmill to the walking capacity of the tested individual was selected correctly. However, additional study of its function should be continued before using special treadmills for patients suffering from heart failure, respiratory failure or intermittent claudication.

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