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Effect of the 6-minute walk test on plantar loading and capability to produce ankle plantar flexion forces

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ABSTRACT

The six-minute walk test (6MWT) is used to evaluate the ambulatory capacity of patients suffering from respiratory disorders, obesity or neuromuscular diseases. Our primary aim was to evaluate the effects of the 6MWT on the postural sway and the ankle plantar flexion forces in healthy subjects.

We measured the ankle plantar flexion forces and the plantar contact area before and after a 6MWT in normal weight and overweight subjects with no history of respiratory, cardiac, and neuromuscular disorders. A post-6MWT sensation of bodily fatigue was evaluated by Multidimensional Fatigue Inventory (MFI) and Pichot fatigue scales. A computerized pedobarographic platform was used to collect the mean plantar contact area, the changes of the center of pressure (CoP) surface and its medial and lateral deviations. In a limited number of subjects, the reproducibility of all the measurements was explored.

In both groups, the 6MWT elicited a sensation of bodily fatigue. It also significantly reduced the ankle plantar flexion forces, and increased both the mean plantar contact area and the CoP surface, the changes being not apparent after 10 min. The post-6MWT lateral CoP deviations were accentuated in normal weight subjects, while an increase in medial CoP deviations occurred in overweight ones. The 6MWT-induced changes in the plantar flexion force and pedobarographic variables were reproducible.

Because this study clearly showed some post-6MWT alterations of the subjects' posture sway of our subjects, we questioned the possible mechanisms occurring that could explain the altered muscle force and the transient destabilization of posture after the 6MWT.

1. Introduction

The six-minute walk test (6MWT) was primarily proposed to explore the cardiorespiratory response of patients suffering from respiratory disorders. As stated by the American Thoracic Society (ATS) [1], "the 6MWT measures the distance that a patient can quickly walk on a flat, hard surface in a period of 6 minutes. It evaluates the global and integrated responses of all the systems involved during exercise, including the pulmonary and cardiovascular systems, systemic circulation, neuromuscular units, and muscle metabolism. . ..Because most activities of daily living are performed at submaximal levels of exertion, the 6MWT reflects the functional exercise level for daily physical activities."

More recently, the 6MWT was also proposed to explore patients with overweight [2–7], sarcoidosis [8,9], multiple sclerosis [10,11], and spinal muscular atrophy [12–14]. Despite "the 6MWT reflects the functional exercise level for daily physical activities" [1], bodily fatigue often occurs after the 6MWT in patients. The evaluation of bodily fatigue was often based on Borg visual analogic scale, and few studies used the Fatigue Assessment Scale questionnaire [8] or the Hammersmith Functional Motor Scale-Expanded [13]. Post-6MWT muscle fatigue was suspected because a reduction of the quadriceps [8], knee flexor, and hip abductor [12] peak muscle strength was reported. However, the ankle plantar flexion forces were never measured despite they represent a more appropriate index of fatigue of the leg muscles which control the foot motion. Moreover, the consequences of the 6MWT on posture were never examined. Hypothesizing that the 6MWT could induce a leg muscle fatigue, a transient destabilization of the posture may also

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be suspected. Several studies have already reported an increased surface of the center of pressure (CoP) after a maximal running exercise [15] and a maximal sustained foot inversion [16], as well as an increased amplitude of CoP deviations after an intensive marching [17] and a high-heeled gait [18].

Our aim was to evaluate the effects of the 6MWT on the ankle plantar flexion forces and on the plantar loading in healthy subjects. We compared subjects with normal weight as well as overweight subjects because numerous previous studies have shown that overweight individuals often have difficulties to stabilize their posture [19], increasing both the medial and the lateral CoP deviations [6,19–21].

2. Materials and methods

2.1. Subjects

Our institutional review board for human studies (CPP Sud Mediterranee 1) approved the protocol and written consent was obtained from the subjects. Thirteen female and eleven male subjects (mean age: 35 ± 6 y) were studied. Twelve had a body mass index (BMI) in a normal range and the others were overweight (Table 1). The podiatrists solely included in this study the subjects who had no major foot malalignment. Some of them had a hallus abducto valgus (n = 4) or planus feet (n = 5). None of the subjects were involved in an exercise program and some of them (8/24) occasionally practiced sport activities (jogging, tennis) for less than 3 h a week. A light meal was acceptable before the early morning or early afternoon 6MWT tests. Despite the subjects were self-reported healthy, to respect the statement by the American Thoracic Society [1], we examined contraindications for the 6MWT which included the following: a resting heart rate (HR) of more than 100 bpm, a systolic blood pressure of more than 170 mmHg, a diastolic blood pressure of more than 100 mmHg, and a percutaneous oxygen saturation (SpO_2) of less than 96%. A pulse oximeter (Spengler Oxy Led, Sofamed, France) gave the instantaneous values of SpO_2 and HR and the blood pressure was measured with a sphygmomanometer (Omron RS3, *OMRON* Sante, Rosny sous Bois, France).

2.2. Pedobarographic measurements

The subjects were bare-footed when standing in double limb stance on the pedobarographic platform for 30 s. The computerized 530 mm × 600 mm strain-gauge platform (WinPOD, Medicapteurs SA, Toulouse, France) consisted of 2304 resistive load cells and its sampling frequency was 100 images s^{-1}. We measured the peak and mean foot pressures, the mean plantar contact area, the ratio of forefoot/rearfoot surfaces, and the CoP surface. The maximum lateral/medial CoP deviations were measured by displacing cursors on the screen of the computer.

Table 1
Morphological and physiological characteristics of normal and overweight subjects at inclusion in the study. BMI: body mass index; SpO_2: percutaneous oxygen saturation. CoP: center of pressure. Values are the mean ± SEM. Symbol # denotes significant intergroup differences ($^{\#}p < 0.05$; $^{\#\#}p < 0.01$; $^{\#\#\#}p < 0.001$).

	Normal weight	Overweight
Number	10	12
Age, y	35 ± 5	39 ± 4
Weight, kg	66 ± 3$^{\#\#\#}$	88 ± 4
BMI, kg m^{-2}	22 ± 1$^{\#\#\#}$	30 ± 1
Systolic blood pressure, mmHg	129 ± 4	137 ± 4
Heart rate, bpm	82 ± 5	90 ± 4
SpO_2, %	98 ± 1	97 ± 1
Maximal ankle plantar flexion force, *N*		
Right foot	140 ± 10$^{\#\#}$	190 ± 10
Left foot	138 ± 15$^{\#\#}$	200 ± 10
Peak plantar pressure, N cm^{-2}	13.0 ± 0.5$^{\#\#\#}$	16.2 ± 0.4
Mean plantar pressure, N cm^{-2}	4.7 ± 0.2$^{\#\#}$	5.6 ± 0.3
Mean plantar contact area, cm^2	162 ± 9$^{\#}$	192 ± 8
Ratio forefoot/rearfoot area	0.97 ± 0.12$^{\#}$	0.63 ± 0.05
CoP surface, mm^2	169 ± 43$^{\#\#}$	355 ± 37
CoP medial deviation, mm	3.9 ± 0.3$^{\#}$	5.2 ± 0.4
CoP lateral deviation, mm	2.1 ± 0.2$^{\#}$	2.9 ± 0.3

2.3. Measurement of the ankle plantar flexion forces

The maximal ankle plantar flexion forces (F_{max}) were measured under isometric conditions using a custom-built device (Fig. 1A). The subjects were seated on a chair with the ankle in a neutral position (95°) when the foot was positioned on the foot plate of the dynamometer. The foot plate was articulated around a horizontal axis allowing only ankle plantar flexion in the sagittal plane. The distal part of the articulated support was connected to a vertically positioned load cell (Scaime model ZF 100, AS Technologies, Langlade, France: linear from 0 to 1000 N). The subjects had no feedback of the developed force and they were also not informed of the reference values so as not to influence their performance after the 6MWT. Before the 6MWT challenge, three 5-s maximal ankle plantar flexion maneuvers were executed by each leg to determine F_{max} values.

2.4. The 6MWT

A "warm-up" period consisting in a first 6MWT was performed 1 h before a second 6MWT during which all the measurements were considered. This practice walk was recommended by the American Thoracic Society [1]. The 6MWT was performed indoors, along a long, flat, straight 40-m corridor whose length was marked every 5 m. Turnaround points were marked with a cone. The required equipments were: a stopwatch, a pulse oximeter, a sphygmomanometer, the Multidimensional Fatigue Inventory (MFI) [22] and Pichot [23] bodily fatigue scales (both validated for French subjects), a source of oxygen and an automated electronic defibrillator. The subjects were asked to walk, and not run, as far as possible for 6 min, back and forth in the hallway. They were permitted to slow down, to stop, and to rest as necessary.

2.5. Protocol

- *Before the 6MWT*: measurements of SpO_2, HR, and arterial blood pressure, maximal ankle plantar flexion force of each foot (3 measurements), and pedobarographic measurements.
- *During the 6MWT*: SpO_2 and HR were measured every min.
- *Post-test measurements*: (1) calculation of the total distance walked, rounding to the nearest meter; (2) measurement of SpO_2, HR, arterial pressure, F_{max} for each foot, pedobarography, and estimation of the post-walk fatigue level using the Pichot and MFI scales. After the 6MWT had stopped, the peak value of the ankle plantar flexion force was measured during the first min. Then, the subject stayed on the pedobarographic platform during the next 2 min. Thus, the successive measurement of the force and pedobarographic variables maximally occurred within 3 min and the subject answered the questionnaire during the further 2 min. The first series of measurements was called R0. Then, F_{max} and pedobarographic measurements were repeated at 10 (R10), and 20 min (R20). In some overweight subjects, a modest SpO_2 decrease occurred at the end of the 6MWT but the oxygen saturation recovered normal (control) values within the first min of the post-6MWT period.

The total distance walked was compared to normal values for women and men [24].