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SHORT COMMUNICATION

Sex-, age-, and height-specific reference curves for the 6-min walk test in healthy children and adolescents

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Abstract The 6-min walk test is a simple and accurate method to measure functional exercise capacity in children. We provide smooth reference curves for the modified 6-min walk test in 696 healthy children and adolescents aged 4–19 years, enabling calculation of sex-, age-, and height-specific *Z*-scores. *Conclusion*: These reference curves will allow more accurate grading of mobility and exercise capacity in sick or disabled children and monitoring the effects of intervention or treatment.

Keywords 6-min walk test · Mobility · Disability · Exercise capacity

Abbreviations

6MWD	6-min walk distance
6MWT	6-min walk test
SD	Standard deviation

Introduction

The 6-min walk test (6MWT) is a simple, efficient, accurate, and safe method to measure functional exercise capacity at submaximal levels of exertion in adults and is used to predict morbidity and mortality from cardiopulmonary disease [2].

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Recent studies have demonstrated its usefulness in the pediatric population [7] and established it as a simple, cost-effective, reliable, and valid test [8]. In children with cystic fibrosis and severe cardiopulmonary disease, the test is used to assess functional capacity, as a proxy measure of pulmonary function, nutrition, and treatment compliance [10]. The 6MWT has also been used to assess physical performance in children with sickle cell disease [6], disease progression in children with muscular dystrophy [9], response to training programs in children with cerebral palsy [5], as well as efficacy of enzyme therapy in mucopolysaccharidosis [3]. We [4], and others [7, 12], have previously reported reference values for the 6-min walking distance (6MWD) for several age categories of healthy children and adolescents. However, using age categories that cover a wide age range does not accurately represent growth, muscle function, and exercise capacity. A normally growing child with repeated 6MWT as part of clinical monitoring will suddenly switch from a higher 6MWD *Z*-score to a lower *Z*-score on the day he/she moves from a younger to an older age category. Growth in height and muscle function are continuous processes and do not occur in blocks. Therefore, the aim of the study was to provide smooth reference curves for the 6MWD in healthy children aged 4 to 19 years, to enable calculation of sex-, age-,and height-specific *Z*-scores for use in clinical practice.

Subjects and methods

The 6MWT measures the distance walked by the participant in 6 min. The modified 6MWT measures the 6MWD using a measuring wheel with interchangeable handlebars of three different lengths to suit the child's height. Healthy and injury-free Caucasian children and adolescents aged 4 to 19 years from kindergartens, elementary, and high schools in Dornbirn and Innsbruck, Austria, were recruited into two studies. Informed consent was obtained from the parents and the child/young person. Both studies were approved by the local ethics committee and used the same standardized methodology for the modified 6MWT. Participants were instructed to walk back and forth around two flagpoles, positioned 20 m apart on a straight course and the 6MWD recorded as displayed on the measuring wheel.

Children in the first study solely used a measuring wheel to record 6MWD (n=528 participants). Their characteristics have been described in detail previously [4]. Another 168 participants, randomized to using the measuring wheel, were recruited from a second study which compared 6MWD covered by children with (modified 6MWT) and without the use of a measuring wheel (conventional 6MWT). The reference data presented here serve as the reference data for the modified 6MWT only.

Children were discouraged from undertaking vigorous exercise for up to 2 h prior to the test, and all were physically examined to attest good physical health. Standardized instructions by a personal instructor were provided during the 6MWT, as previously described [4]. Children wore light clothes and sneakers and were refrained from jogging or running during the test.

To create smooth sex-specific 6MWD centile charts for age and height, we applied the Altman model [1], which uses the absolute residuals of the dependent variable to determine the standard deviation (SD) equation, since SD can vary naturally with age and height. First, the best fitting 6MWD mean curve (50th centile) was obtained by regression analysis. To determine the best fitting SD equation for either sex, the mean of absolute residuals was taken, as on this occasion, no specific equation fitted the absolute residuals. This was then multiplied by $\sqrt{(\pi/2)}$ to create the SD and subsequently regressed against age and height. Individual *Z*-scores (SD scores) can be calculated by inserting age or height in the equations for mean and then using the formula: $(x-\text{mean})/\text{SD}$.

Results

A total of 368 boys and 328 girls completed the test, while 122 children declined participation. No untoward events required the test to be aborted prematurely. The best fitting equations describing the smooth age- and height-related increment in 6MWD are given in Table 1. The sex-specific centile curves created from these equations, showing the 2nd, 50th, and 98th centiles for age and height, are shown in Fig. 1. As an example of the use of the formula in Table 1, a 10.4-year-old girl, with a height of 1.38 m covering 658 m in 6 min, would plot on the 50th centile for age-specific (0 SD) and between 50th and 75th centile on the height-specific centile chart (+0.39 SD).

In age-specific centile curves for girls, the 6MWD increased between 4 and 11 years of age, plateaued thereafter and dipped slightly in those aged 15 years and above. In boys, the 6MWD increased from 4 to 19 years of age with the steepest rise between 6 and 14 years of age (Fig. 1). In the height-specific curves, the 6MWD plateaued at a body height of approximately 1.60 m in girls and 1.85 m in boys. Overall and as expected, boys covered greater 6MWD than girls, both relative to age and height (p<0.001).

Discussion

This study presents smooth reference curves for the 6MWT in a large cohort of healthy Caucasian children aged 4 to 19 years for easy use in clinical practice and enables the calculation of sex-, age-, and height-specific *Z*-scores. These centile charts can be used to measure exercise capacity in both healthy and

Table 1 Sex-specific equations to calculate mean and SD score of the 6MWD (meters) for age (years) and height (meters)

	Centile/SD	Equations	R^2
Girls			
Age	50th	$320.7497+11.8821\times\text{age}+7.1593\times\text{age}^2-0.6661\times\text{age}^3+0.0161\times\text{age}^4$	0.48
	SD	60.374	
Height	50th	$-2554.9530+5112.4615\times\text{height}-2638.1319\times\text{height}^2+440.6610\times\text{height}^3$	0.44
	SD	61.450	
Boys			
Age	50th	$\exp(6.765497294541412-2.846474124886012/\text{age})$	0.52
	SD	63.075	
Height	50th	$-574.2609+1378.1846\times\text{height}-362.3404\times\text{height}^2$	0.47
	SD	65.057	

Equations for the 50th centile (predicted mean) are given; 2nd and 98th centiles are created by predicted mean±2.05 SD. On this occasion, no specific equation fitted the absolute residuals; hence, the mean of the absolute residuals was taken and multiplied by $\sqrt{(\pi/2)}$ to create the SD. Sex-specific centile charts for age and height are available from the authors. To calculate an individual's *Z*-Score (SD Score), the patient's age or height first has to be entered in the sex-specific mean equations. Then the *Z*-score=(x−mean)/SD

chronically ill children, and assess response to intervention, in particular in children with physical disabilities and varying disease severity in whom performing a full cardiopulmonary exercise test could prove challenging. In addition, the curves may be used for the clinical monitoring of disease progression in children with musculoskeletal conditions such as muscular dystrophy [9] and for rehabilitation following fractures or illness. The availability of age- and height-specific *Z*-scores for 6MWD will also assist in measuring even more accurately the change in exercise capacity over time, during clinical monitoring, as a response to intervention [5], or in clinical research in children and young people.

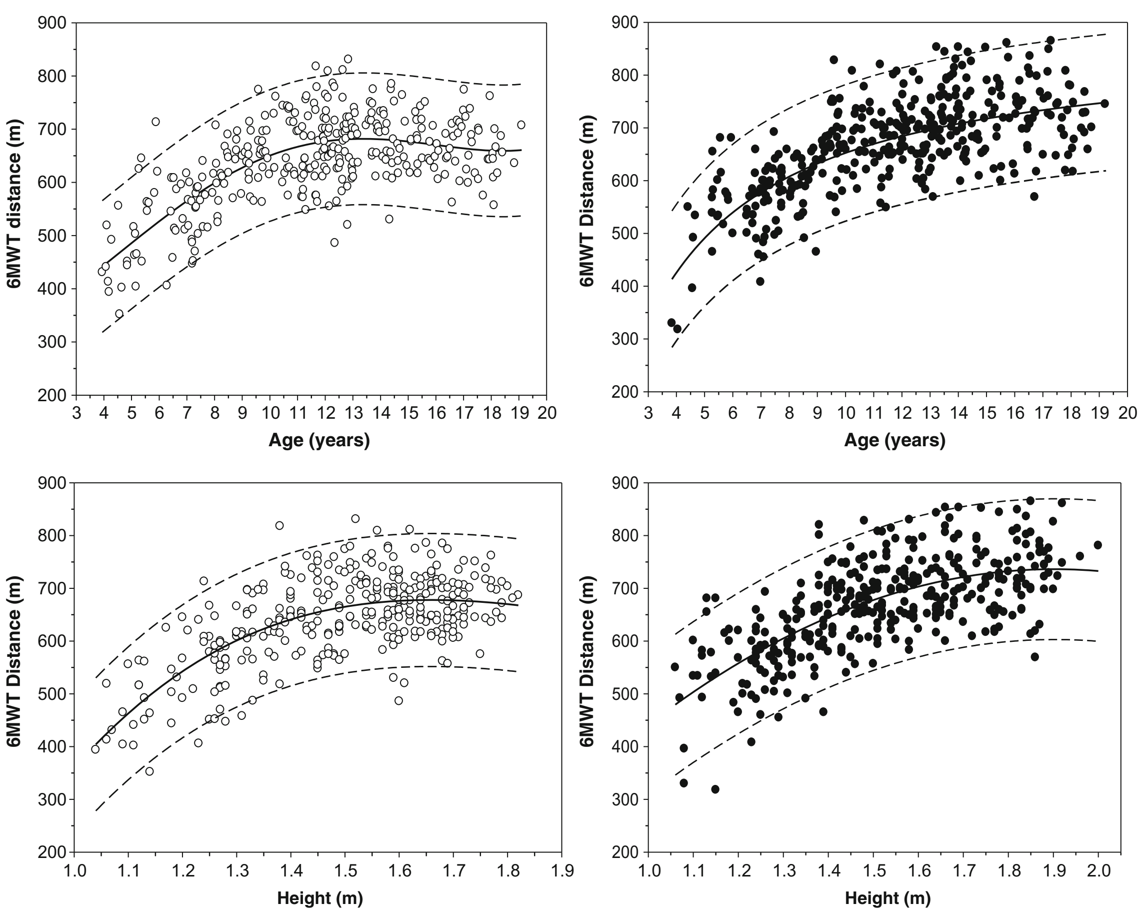

Fig. 1 Reference curves for the 6-min walk test (6MWT) distance in girls (*white circles*) and boys (*black circles*) for age (*top panels*) and height (*bottom panels*). Depicted curves represent the mean as well 2nd and 98th centiles

Older and taller children are generally expected to cover a greater distance; however, we observed a slight decline in 6MWD in female teenagers, a phenomenon recently described [12]. While motivation may be a contributing factor, we speculate this decline is caused by estrogen-related increments in fat mass [11] thus contributing to the widening sex disparity in response to exercise in puberty.

A limitation of this study was that it included only Caucasian children. Although the 6MWT was performed only once in each participant, high test-retest reliability has been demonstrated in healthy children in a recent study, and hence, we do not consider this to have a significant impact on our results [8]. Although the validity of conventional 6MWT in measuring exercise tolerance and endurance in healthy children has been previously demonstrated [8], any new functional test needs to be validated for use in specific conditions.

In conclusion, we present smooth age- and height-specific reference curves for use in daily practice and provide equations that allow the calculation of *Z*-scores for the 6MWD in children from 4 to 19 years.

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Conflict of interest The authors declare no potential conflict of interest.

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