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One-minute sit-to-stand test as an alternative tool to assess the quadriceps muscle strength in children

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ABSTRACT

Background

Clinical tools for assessment of the skeletal muscle strength are scarce and have rarely been validated in children. The aims of this study were to verify the construct validity of the one-minute sit-to-stand test (1-MSTST) to evaluate the quadriceps strength in healthy children between 12 and 18 years old and to correlate these outcomes with the anthropometric parameters.

Methods

Healthy children were recruited and consecutively performed 1-MSTST and maximal voluntary contraction of the quadriceps (QMVC).

Results

Eighty-three children (15 ± 2 years old) were analyzed. Contrarily to the QMVC, neither the number of 1-MSTST repetitions nor the sit-to-stand work (1-MSTST expressed as the product of body weight) differed between genders. The QMVC was not correlated with the number of repetitions (rho = −0.056; $P = 0.617$) but correlated with 1-MSTST when expressed as a product of body weight ($r = 0.491$; $P < 0.001$). The QMVC was also correlated with age ($r = 0.314$; $P = 0.004$), height ($r = 0.672$; $P < 0.001$), weight ($r = 0.721$; $P < 0.001$) and BMI ($r = 0.451$; $P < 0.001$) whereas 1-MSTST did not correlate with any of these parameters. The leg length was related to the results of both tests.

Conclusion

We demonstrated that the one-minute sit-to-stand test can be considered as a valid and valuable alternative to evaluate the muscle strength when expressed as the product of body weight.

1. Introduction

Skeletal muscle dysfunction is observed in various paediatric diseases such as asthma [1], bronchopulmonary dysplasia [2], cystic fibrosis [3], primary ciliary dyskinesia or congenital heart disease [4]. In addition, the muscle strength is an important predictor of health outcomes during childhood [5] and is highlighted as an independent and powerful predictor of better insulin sensitivity in children [6]. Measuring muscle strength is therefore important in clinical practice.

Manual muscle testing was regularly used in the past but the sensitivity of this testing is poor as illustrated by the inconsistent relationship with quadriceps isometric strength [7]. At present, the isokinetic dynamometry has become the gold standard tool to quantify muscle strength [8]. However, hand-held dynamometry examinations where a resistance is directly applied either by the operator or by the use of straps, is a valid and reproducible alternative to measure quadriceps strength [8]. The hand-held dynamometry is particularly useful in clinical practice when the isokinetic examination of the quadriceps is difficult to implement. Even if the use of belt-stabilization improves the precision [9] and the inter-rater reliability of this latter examination [10], some practical limitations were addressed related to the hand-held dynamometry such as the need of fixed gauge and the underestimation of forces beyond 250 N [9]. Moreover, the devices to perform the evaluation are expensive.

For a long time, to sit-to-stand from a chair was suggested as a quick, easy and inexpensive test to assess peripheral muscle performance of lower limbs [11,12]. The one-minute sit-to-stand test (1-MSTST) was demonstrated as a valid and reliable tool to quantify the lower limb muscle strength in elderly people and in various chronic disease conditions [11,13–15]. In addition, the number of repetitions expressed as the product of body weight was demonstrated to be a better outcome than the absolute number of repetitions [16]. Recently, this test was also validated in children to quantify the cardio-respiratory response to exercise [17] and predicted values were deter-

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mined. However, the relationship between the 1-MSTST and the lower limb muscle strength has never been verified in children.

The hypothesis is that the 1-MSTST could be a good alternative to evaluate the lower limb muscle strength in children. The aims of this study were to verify the construct validity of the 1-MSTST expressed in absolute value and in product of body weight to evaluate the quadriceps strength in healthy children between 12 and 18 years old (primary outcome) and to correlate these outcomes with the anthropometric parameters (secondary outcomes).

2. Method

2.1. Subjects

Healthy children from 12 to 18 years were recruited in one high school from November 2017 to February 2018. The participation in the national physical education program at school was the only inclusion criterion. The exclusion criteria were a diagnosis of chronic lung, cardiac or neuromuscular disease or a motor disability based on parents' answer to standardized questions, to be overweight (BMI higher than 85th percentile for children of the same age and sex) [18] or conditions limiting the maximal extension of the knees or prohibiting the closed-glottis pushing. The subjects should not have done physical activity for one hour preceding the experiments.

The study was approved by the local Ethic Committee from *Cliniques universitaires Saint-Luc* in Brussels (2017/26JAN/046 – B403201731090). It was conducted according to the Declaration of Helsinki. Parents and children gave their written inform consent prior to the beginning of the experiment.

2.2. Design of the study

It was a prospective study following the Standards for Reporting of Diagnostic Accuracy Studies (STARD). The children performed successively a measurement of the quadriceps strength with a belt-stabilized hand-held dynamometer and a one-minute STST. The order of the tests was not randomized and both were interspersed by a 10-minutes break based on the high resistance to fatigue of children [19]. All the tests were performed by the same trained physiotherapist (LP).

2.3. Tests

2.3.1. One-minute sit-to-stand test (1-MSTST)

The one-minute STST was performed based on the recently validated protocol in children [17]. Children put their hands on their hips and they had to stand up and sit down completely and as many times as possible from a chair (height = 46 cm) without arm rests during one minute. A demonstration test was previously performed by the evaluator and standardized instructions were given to the children before the test. No encouragements were provided during the test. Children were not allowed to use their arms as support. Rest periods were permitted during the one minute period but the countdown timer was not interrupted.

2.3.2. Quadriceps maximal isometric voluntary contraction (QMVC)

A hand-held dynamometer (MicroFET2, Hogan Health Industries, UT, USA) was used to measure the maximal isometric voluntary contraction of the quadriceps (QMVC) from the dominant leg for five attempts [20]. The two first attempts were considered as training. The patient sat comfortably on the examination table with a high-density triangular corner cushion under the knees as a counter-support for the knees. Hip and knee were positioned at 90° flexion. The dynamometer was fixed between the leg of the child and the belt-stabilization to prevent any operator bias. The belt was positioned 5 cm above the medial malleolus of the tibia. After measuring the lever distance (knee joint – dynamometer) with a tape measure, a knee extension was asked to the children and a vigorous encouragement was performed during all the isometric contraction (contraction during 4 to 6 seconds).

2.4. Outcomes

Anthropometric parameters were noted. The number of completed repetitions was recorded at the end of each 1-MSTST and expressed in absolute value. This number was also expressed as the product of body weight (1-MSTST × weight) to provide an index of total work (1-MSit-to-standwork) [16].

The best value from the three last attempts for each leg extension was retained to calculate the QMVC expressed as the maximum force momentum (force × lever distance; [Nm]).

A finger pulse device (Onyx, Nonin, USA) was used to record heart rate (HR). It was expressed in absolute value. The change of HR was calculated by the difference between initial and final values divided by the initial value.

2.5. Statistical analyses

The sample size determination was based on the detection of a 0.300 correlation coefficient between the quadriceps strength and 1-MSTST with a power of 80% and an alpha level of 0.05. The number of participants anticipated for the study was 84.

Data were computed using SPSS 25.0 (IBM software) for Windows. Descriptive analysis of demographic parameters and results of both tests was performed. These data were presented as mean and standard deviation or median and minimum and maximum after verifying the normality of the distribution by Kolmogorov–Smirnov test. The comparisons of similar data between boys and girls were performed by Student *t*-test to verify if there were gender differences. The relationships between different outcomes were verified by the Pearson's or Spearman's correlation coefficient depending on the distribution of the data. Intensity of the relationship was interpreted from the correlation coefficient as poor (< 0.50), moderate (from 0.50 to 0.75), good (from 0.75 to 0.90) or excellent (> 0.90) [21]. A lower *P*-value than 0.05 was considered as significant.

3. Results

Eighty-three children were analyzed (Fig. 1). All recruited children completed the tests. Demographic parameters of the children and results of both tests are displayed in Table 1. The boys were taller with longer legs and also heavier than the girls. The QMVC was greater in boys than in girls. However, neither the number of repetitions nor the one-minute sit-to-stand work differed between genders.

The relationship between 1-MSTST and QMVC was not verified in our sample of children (rho = −0.056; $P = 0.617$) as it is illustrated in Fig. 2A. The same result was observed for boys (rho = −0.035; $P = 0.827$) and girls (rho = 0.003; $P = 0.983$). However, the QMVC was positively correlated to 1-MSTST when the latter was expressed as a product of body weight ($r = 0.491$; $P < 0.001$) (Fig. 2B). The QMVC was also correlated with age ($r = 0.314$; $P = 0.004$), height ($r = 0.672$; $P < 0.001$), weight ($r = 0.721$; $P < 0.001$) and BMI ($r = 0.451$; $P < 0.001$) whereas the 1-MSTST score did not correlate with any of these parameters.

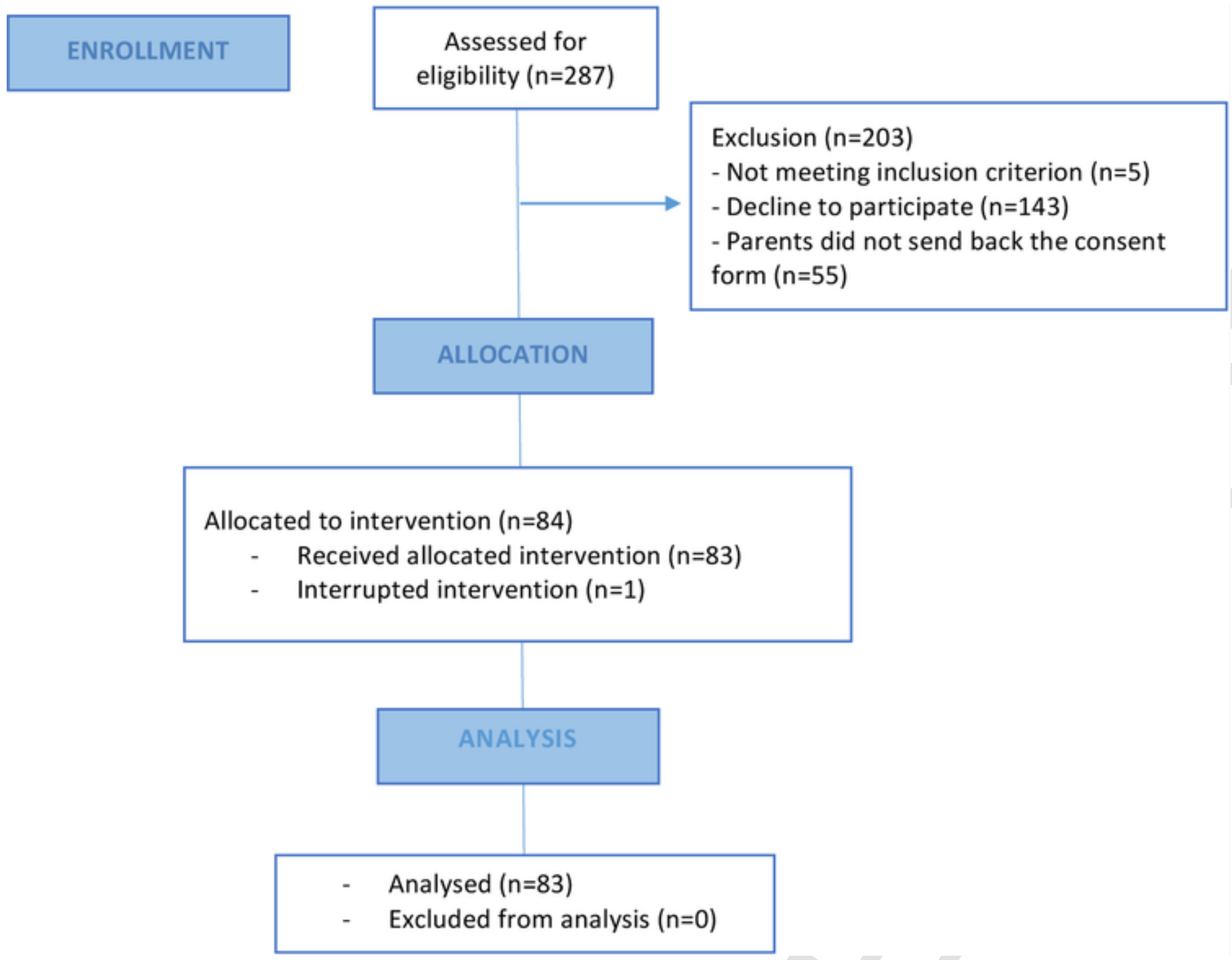

Fig. 1. Consort flow chart of the study.

Table 1
Demographic data of the children and their results in both tests.

Parameters	All children	Boys ($n=42$)	Girls ($n=41$)	P-value
Age (y)	14.8 ± 1.7 [14.4;15.1]	14.5 ± 1.7 [13.9;15.0]	15.1 ± 1.6 [14.6;15.6]	0.107
Height (cm)	1.69 ± 0.10 [1.67;1.72]	1.72 ± 0.13 [1.68;1.76]	1.66 ± 0.06 [1.64;1.68]	0.009[a]
Weight (kg)	58.1 ± 10.4 [55.8;60.4]	60.5 ± 12.7 [56.5;64.4]	55.7 ± 6.7 [53.5;57.8]	0.035[a]
BMI (kg.m^{-2})	20.2 ± 2 [19.7;20.6]	20.2 ± 2.6 [19.4;21.0]	20.1 ± 1.8 [19.5;20.7]	0.809
Leg length (cm)	38.8 ± 2.9 [38.2;39.5]	39.8 ± 3.1 [38.9;40.8]	37.8 ± 2.4 [37.1;38.6]	0.001[a]
1-MSTST (repetitions)	50 ± 11 [48;52]	49 ± 11 [45;52]	51 ± 10 [48;54]	0.347
1-MSTST × weight (rep × kg)	2875 ± 762 [2709;3042]	2929 ± 897 [2649;3208]	2820 ± 601 [2631;3010]	0.521
ΔHRi-f (%)	59 ± 27 [53;65]	59 ± 31 [48;68]	59 ± 23 [51;66]	0.973
QMVC (Nm)	152.3 ± 44.4 [142.6;162.0]	163.9 ± 51.6 [147.9;180.0]	140.3 ± 31.9 [130.2;150.4]	0.014[a]

BMI: body mass index; 1-MSTST: one-minute sit-to-stand test; HR: heart rate; i: initial; f: final; r: rest; QMVC: quadriceps strength; Nm: Newton meter. Data are expressed by mean ± standard deviation and confidence interval between brackets.

[a] Significant difference.

The leg length was related to the results of both tests. The longer the leg length, the greater the quadriceps strength expressed in Newtons as illustrated by the moderate and positive correlation between these outcomes ($r = 0.551$; $P < 0.001$). On the other hand, an inverse but poorer relationship was found between leg length and 1-MSTST (rho = −0.318; $P = 0.003$).

4. Discussion

The results of this study provide interesting information for researchers and clinicians. Indeed, when 1-MSTST was expressed as a product of body weight, a significant correlation was found with the QMVC. It means that the construct validity of this outcome was verified and that can be considered as a valuable alternative to assess and follow the QMVC. However, the absolute number of repetitions per-

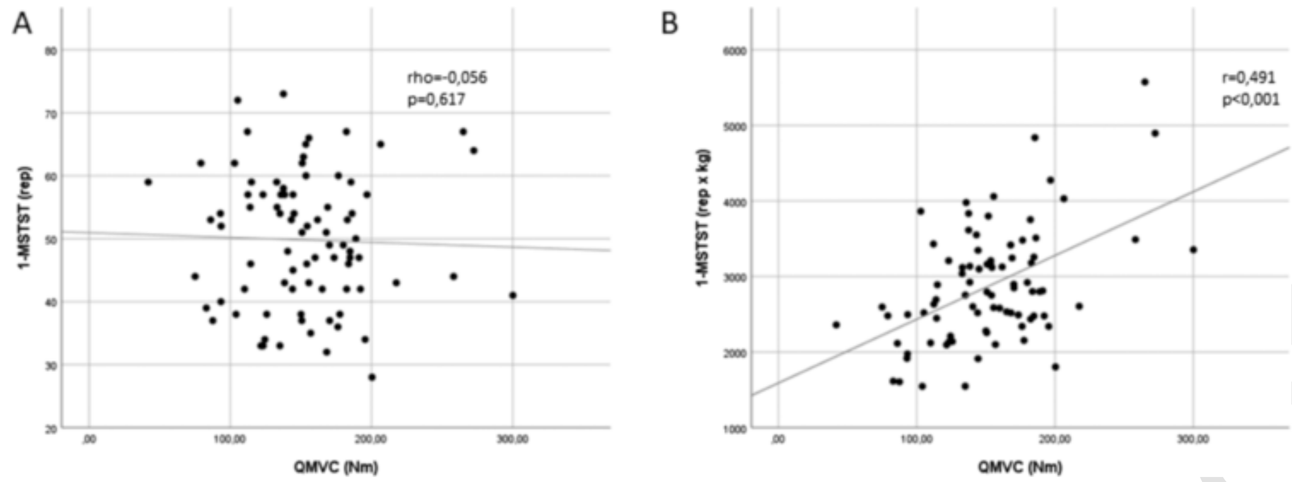

Fig. 2. Relationship between the quadriceps maximal voluntary contraction (QMVC) and the result of the one-minute sit-to-stand test expressed as the number of repetitions (A) or as the product of the body weight (B).

formed during 1-MSTST is not sufficient to estimate the quadriceps strength in healthy children.

The muscle strength is widely quantified among physiotherapists or physicians in daily clinical routine, rehabilitation and research. Firstly, its evaluation is justified in different acute or chronic clinical conditions. For instance, after severe burns, muscular losses are observed early [22] and they persist for a long time after burn injury [23]. In cystic fibrosis, it is also well-known that the muscle strength can be affected by nutritional and respiratory impairments which are a limiting factor for activities of daily life [3,24–26]. The follow-up of the muscular strength is also useful in children due to the possible changes in muscle mass and muscle fiber size related to various diseases, as for kidney transplant recipients or children with epilepsy who were taking anticonvulsant therapy [26,27]. Secondly, in rehabilitation, muscle strength is also regularly used to quantify the effect of an exercise program [28,29]. Thirdly, in research, this evaluation offers the way to highlight some important relationships. Indeed, grip strength was associated with a wide range of health outcomes and risk score [30].

Despite the interest of the assessment of muscle strength, it can be difficult to perform. Indeed, the muscle strength evaluation requires costly equipment (isokinetic dynamometers) and strictly standardized procedures (hand-held or isokinetic dynamometers). The measurement changes if the examiner holds the hand-held dynamometer in stationary position or pushes it against the active limb [9,31]. For these reasons, simpler and standardized surrogates are appreciated. Different STSTs which can be easily performed have been already correlated to the quadriceps strength in various population as in elderly [32–35]. Moreover, moving from sitting to standing is a common activity of daily living. An advantage of the 1-MSTST compared to direct measurement of the muscle strength with hand-held dynamometer is the combination of the muscle strength assessment and the evaluation of the functional status [36–38].

Interestingly, the 1-MSTST has been recently validated to estimate the cardio-respiratory demand during exercise in children [17]. But, until now, the validity of this test to evaluate the quadriceps strength had never been verified in this population. The results of our study demonstrated a relationship between the number of sit-to-stand movements expressed as a product of body weight (1-MSTST × weight) and the quadriceps strength, meaning that the clinician can now estimate the quadriceps strength and follow its evolution in the time by using this outcome.

We also observed a relationship between QMVC and age, weight, height and BMI. These correlations were expected [26,27,4]. Conversely and as expected [17], the 1-MSTST did not demonstrate such relationships. The shorter displacement of the center of gravity when the leg is shorter can explain the inverse correlation between 1-MSTST and leg length. Moreover, the lever distance increased with the leg length and that can explain the greater QMVC.

The QMVC measured in our study was close to the reference values obtained in children from 4 to 17 years by Hebert et al. [27]. Likewise, the number of repetitions performed during the 1-MSTST by the children in our study was also similar to the median number of repetitions from the population based reference values determined by Strassmann (25–75th percentile 41–57) in young men aged from 20 to 24 years [39] and similar to the reference values found in young children aged from 6 to 12 years (50 ± 13 (submission in progress)). To our knowledge, there are no reference values for the 1-MSTST more suitable to our sample of children. The cardio-respiratory demand illustrated by the change in HR during the 1-MSTST was in accordance with a previous study where children performed the 1-MSTST with the same protocol [17]. The possibility to combine the assessment of quadriceps strength and cardio-respiratory demand in a simple, easy-to-perform test is an important advantage of the 1-MSTST.

4.1. Study limitations

Some limitations need to be addressed for this study. Since we did not recruit children with very low muscle strength, caution should be taken when extrapolating our results to children with severe muscular limitations. The same comment can be done for obese children. Indeed, they were excluded in our study but many obese children can be found in some country. In addition, the physical activity level of the children could be a factor implied in this relationship though not assessed in this study.

Another limitation could be the non-randomization of the tests. Due to this choice, we cannot be sure that the first test did not influence the result of the second one.

In conclusion, we demonstrated an advantage for using the calculation of one-minute sit-to-stand work (1-MSTST expressed as the product of body weight) over simple number of repetitions during the 1-MSTST to estimate the quadriceps strength in children. The one-minute sit-to-stand work can be considered as a valid and valuable alternative to assess and follow the QMVC in daily clinical routine, rehabilitation and research. In addition, the 1-MSTST offers multiple indications with its previously demonstrated validity for the assessment of the cardio-respiratory demand in children.

Data sharing statement

The individual participant data (after de-identification) that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

Ethical approval

The study was approved by the local Ethic Committee from *Cliniques universitaires Saint-Luc* in Brussels (2017/26JAN/046 – B403201731090).

The study was performed in the *Cliniques universitaires Saint-Luc*, Brussels, Belgium.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Contributions

GR: substantial contributions to the conception, design of the work and the acquisition, analysis and interpretation of data for the work; drafting the work and revising it critically for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

LP: substantial contributions to the conception, design of the work and the acquisition, analysis and interpretation of data for the work; drafting the work and revising it critically for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

NA: substantial contributions to the conception of the work and the analysis and interpretation of data for the work; revising the work critically for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

WP: substantial contributions to the conception of the work and the analysis and interpretation of data for the work; revising the work critically for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

GC: substantial contributions to the conception, design of the work and the analysis and interpretation of data for the work; revising the work critically for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Disclosure of interest

The authors declare that they have no competing interest.

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