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**Original Article**

# Assessment of cardio-respiratory fitness using age-adjusted squat test models

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**Abstract**
*Problem Statement*: The Ruffier Dickson test is widely utilized across various domains including sports science, medicine, fitness, and physical education. However, it tends to yield underestimated results when applied to young patients. *Approach*: This research aims to refine the Ruffier Dickson index model by considering the normal heart rate differences between adults and young patients. *Purpose*: The study seeks to assess the efficacy of the age-adjusted squat test in predicting maximal oxygen uptake in children and adolescents. *Material and methods:* 683 children of 6 – 17 years old from a million population city in Western Ukraine have been involved in the study. All the pupils were good in health, i.e. they met common criteria determined by the Ministry of Education and Science and the Ministry of Healthcare of Ukraine and therefore they were admitted to participate in the schools' physical education lessons according the standard State program of Physical Culture. *Results*: The original Ruffier – Dickson index values, as well, as its values determined according the modified model, which makes possible to take into account an age of children and adolescents were calculated. The Ruffier index appeared more sensitive to variation of a pulse rate than the Dickson index. The range of common values of the Ruffier index is approximately 24 (2 − 26) and the Dickson index − 15 (5 − 20). *Conclusions:* The Ruffier – Dickson squat test with corresponding age-generalized indexes is recommended as a suitable protocol to provide an easy and fast self-evaluation of the maximal oxygen uptake in children and adolescents as well, as in adults.
**Key Words: children, adolescents, heart rate, validity**

## Introduction

About seventy years ago, Dr. J. E. Ruffier and Dr. J. Dickson developed a prompt squat test of resistance of a heart to the physical effort (Dickson, 1950). The Ruffier index is calculated according the formula (Ruffier, 1951):

$$RI = \frac{4(n_0 + n_1 + n_2) - 200}{10}, \qquad \text{(Eq.1)}$$

where $n_0$ is a number of heart beats during 15 s at rest, $n_1$ − just after the end of the effort (30 squats during 45 s), and $n_2$ − in 45 s after the end of the effort. The resistance of a heart to the physical effort is 'excellent', when the index magnitude is smaller than 3.5, 'good' − within 3.5 and 6.5, 'average' (6.5 − 9.5), 'poor' (9.5 − 14.5), and 'very poor', when the index magnitude is greater than 14.5.

*Prediction of the maximal oxygen uptake*

Because the test is valid, easily reproducible, simple, does not need any equipment but a timer, it is still popular in physical education and sports medicine. Furthermore, the Ruffier−Dickson test has been identified as a suitable protocol to provide an easy and fast self-evaluation of the maximal oxygen uptake (Sartor et al., 2016; Zanevskyy et al., 2016). Maximal oxygen uptake estimation is essential in sports, clinical and home settings because it is considered the best index of cardio-respiratory fitness, which expresses the maximal aerobic power of an individual (Bassett & Howley, 2000; Sartor et al., 2013; Fletcher et al., 2013). The importance of the maximal oxygen uptake as predictor of cardiovascular disease and mortality has been recently highlighted by a scientific statement issued by the American Heart Association (Kaminsky et al., 2013).

During last decades, the test was fruitfully used in different spheres of sports science, medicine, fitness, physical education and others. Bruneau et al. (2009) showed that the ankle-to-brachial index can be easily performed by all physicians using the Ruffier – Dickson index. The test is an easy procedure to attain moderate exercise at the bedside for physicians who do not have an ergometer. It is a simple bedside exercise helpful or sufficient for the diagnosis of the endofibrosis.

Oliveira et al. (2010) concluded that it is possible to use the heart rate period of recovery after the Ruffier − Dickson test for the evaluation of training level in sportsmen. They noticed in male physical education students a good correlation ($r$ = −0.586, $p$ = 0.003) between the Ruffier − Dickson index and the maximal oxygen uptake estimated indirectly using 2400 m treadmill test. Modave et al. (2017) founded moderate


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associations between the Ruffier index and the maximal oxygen uptake. They defined the Ruffier index as a useful method for quickly identifying individual with poor fitness, but not to discriminate fine levels of fitness gradation. To achieve higher correlation, refined scoring tools were recommended.

Using the Ruffier − Dickson test, Piquet et al. (2000) studied the recovery periods of blood flow parameters in muscles after anaerobic exercise, instantaneous and mean blood flow velocity curves. They observed significant correlation between femoral stroke distance and Ruffier − Dickson index ($p$ = 0.045). Supervising a performance of the Ruffier test, Cisse et al. (2006) undertook a study of body composition and cardiovascular parameters interdependence in long sprint running athletes.

Inoue & Nakao (1996) predicted maximal oxygen uptake by squat test for men and women. The squat tests for 1 or 1.5 min were adopted as simple endurance tests with superior reproducibility. For example, the equation relating the maximal oxygen uptake (ml/kg/min) to the score of the squat test for 1.5 min in men was:

$$\dot{V}O_2\,max = -0.261X + 85.19 \ \ (r = -0.820,\, p < 0.001), \qquad \text{(Eq.2)}$$

where $X$ is score of the squat test, $r$ is Pearson correlation, and $p$ is significance. In result, they suggested that maximal oxygen uptake can be estimated not only by the step test for 1, 2 or 3 min but also the squat test for 1 or 1.5 min.

Guo et al. (2018) undertook a study which provides strong support for using the Ruffier test in clinics as an accurate, regular, and inexpensive preventive medicine screening tool to measure and track cardio-respiratory fitness, and to allow to quantify physical activity as a vital sign. They derived the best-performing model in predicting of maximal oxygen uptake via submaximal exercise testing with formula as follows:

$$\dot{V}O_2\,max = 3.0143 + 1.1585S - 0.0248P_0 / H + 118.7611(P_1 - P_2)/ A^3, \qquad \text{(Eq.3)}$$

where $P_0$ is resting heart rate before squatting (min$^{-1}$), $P_1$ is peak heart rate after squatting, $P_2$ is recovery heart rate 60 seconds after squatting, $S$ equals 0 for women and 1 for men, $H$ is body height (m), and $A$ is age (yr). The age-adjusted recovery heart rate index fitness had the highest intraclass correlation coefficients of 0.9 and Pearson's correlation coefficients of 0.71, which suggested the modified squat test, can reasonably assess cardiopulmonary fitness for the older adult. The best-performing model using these two features predicted individuals' cardio-respiratory fitness levels with an adjusted $R^2$ = 0.637, sensitivity of 0.79, and specificity of 0.56 (Zanevskyy et al., 2017).

Yeh et al. (2018) investigated the reliability and validity of a modified squat test and established a regression model for predicting aerobic fitness in the older adult. The modified squat test is a valid and reliable field test and thus can be an option to assess the cardiopulmonary fitness level of healthy older men in clinics and communities. The best index is age-adjusted recovery heart rate with the formula as follows:

$$\dot{V}O_2\,max = 16.781 + 16.732t + 0.02467l_a, \qquad \text{(Eq.4)}$$

where $t$ is age-adjusted recovery heart rate (min$^{-1}$), $l_a$ is physical activity level as a score of PASE (1991) questionnaire.

Sangirolamo et al. (2021) revealed effects of a hybrid multi-professional intervention on morphological and cardiorespiratory parameters in overweight or obese females. Similarly, Casolo et al. (2019) made clear effects of a structured recess intervention on physical activity levels, cardiorespiratory fitness, and anthropometric characteristics in primary school children.

Tychyna et al. (2024) studied an impact of military-applied sports on cardiorespiratory indicators of cadets in military higher education institutions. Tous-Espelosin et al. (2023) using a tertiary analysis in the CORTEX-SP study showed in what a way a higher cardiorespiratory fitness impacts the clinical symptoms in individuals with schizophrenia.

Barbieri et al. (2019) carried out a comparison of cardiorespiratory responses between CrossFit practitioners and recreationally trained individual. Developing these investigations, Junior et al. (2019) studied cardiorespiratory responses in maximal cycle ergometry in cardiac rehabilitation. Mauricio et al. (2017) determined a cardiorespiratory and nutritional status through anthropometric patterns of health in 12-14-year-old schoolchildren in urban and rural areas of the Araucania Region, Chile. Chen et al. (2016) presented effects of brisk walking and resistance training on cardiorespiratory fitness, body composition, and lipid profiles among overweight and obese individuals.

To assess cardiorespiratory fitness with 10 squats in 15 s, Trovato et al. (2023) realized a feasibility study using a modified isoinertial-based Ruffier Test in Healthy Individuals. Both classic and isoinertial Ruffier tests were administered to thirty-five healthy young adults. The study evidenced the feasibility of the isoinertial Ruffier test to measure cardiorespiratory fitness through a quick, safe, and short squat test easy to perform in fitness centers and primary care clinics.

Ruffier test and corresponding Ruffier index of resistance of a heart to an effort are rather popular in sports, physical education, rehabilitation etc. From the very beginning of the academic year 2009-2010, Ruffier test was introduced in Ukraine as a formal method of classification into the categories of a health status of 6-16 years old pupils. According to these categories, a program of physical education lessons was corrected. As a result of this, a great part of pupils (somewhere more than a half) appeared according to the program in the weakest (named 'special') group with a nominal (near zero) level of physical activity. Even some young sportsmen were "condemned" to a special group according to results of Ruffier test. Teachers of physical

education, pupils, and parents need an explanation of the problem and a way of this decision (Zanevskyy et al., 2023).
The **research aimed** to estimate validity of the age-adjusted squat test in prediction of maximal oxygen uptake in children and adolescents.

## Materials & methods

*Participants*

683 children of 6 – 17 years old from a million population city in Western Ukraine have been involved in the study. All the pupils were good in health, i.e. they met common criteria determined by the Ministry of Education and Science and the Ministry of Healthcare of Ukraine and therefore they were admitted to participate in the schools' physical education lessons according the standard State program of physical culture. This study was approved in advance by Ethical Committee of Lviv State University of Physical Culture, Ukraine. Parents of each the pupil participant voluntarily provided written informed consent before participating.

*Procedure*

The procedures followed were in accordance with common standards of the Ethical Committee on Human Experimentation. At the very beginning of Academic Year all the pupils were tested according the Ruffier – Dickson procedure. A number of heart beats during 15 s at rest was measured. Then, a number of heart beats just after thirty squats during 15 s and in 45 s after the end of squats were measured, too. These measurements were done using a usual stop-watch timer.

*Data collection and statistical analysis*

An original Ruffier – Dickson index values (Dickson, 1950; Ruffier, 1951), as well, as its values determined according the modified model, which makes possible to take into account an age of children and adolescents were calculated (Zanevskyy, & Zanevska, 2013). Calculations graphical plotting were done using MS Excel computer program.

## Results and Discussion

*Generalized Ruffier index*

Despite a great attention that researchers pay to the problem of age-adjusted cardio-respiratory fitness models for elder people, the same problem regarding young patients is actual in sport sciences and medicine. Dr. J.E. Ruffier and Dr. J. Dickson used their test for adults, but after them the test was used for children and adolescents, too (Dickson, 1950; Ruffier, 1951). For example, the Ukrainian Ministry of Education and Science and Ministry of Health decided to divide pupils on the lessons of physical education into cardio-respiratory fitness levels using the Ruffier test. The test showed poor results of cardio-respiratory fitness for school children. As a result, a great part of pupils were "condemned" to the clinic group with a nominal (almost zero) level of physical activity on the lessons and community. Teachers, pupils, and parents needed an explanation of the problem and a way of its solution.

Zanevskyy and Zanevska (2013) found a cause why children and adolescents show increased magnitudes of the index in comparison with adults: a normal heard rate at rest in childhood and adolescence is greater than in adults. For example, a six years old patient with a normal heard rate at rest about 102 beats per minute (bpm) gets values of the Ruffier index (Eq.1) greater than 10.6 because heard rate after squats is greater than at rest. An adult patient with a normal heard rate at rest about 70 bpm gets an index value greater than 1.0. When $n_1 = 1.5n_0$ and $n_2 = 1.1n_0$, a six years old patient's index equals 16.7 and adult's – 5.2, i.e. two patients under the same normal conditions are evaluated in a very different evaluations − as 'very poor' (child) and 'good' (adult). Corresponding generalized formula of the age-adjusted Ruffier index for young patients of 6-17 years old was derived as follows:

$$RI_C = \frac{C(n_0 + n_1 + n_2) - 200}{10}, \qquad \text{(Eq.5)}$$

where $C$ is a correction coefficient, which value is smaller for younger patients (Table 1). For the age of 17 years old, its value equals four like the original formula for adults (Eq.1). The original Ruffier index formula was corrected multiplying a sum of heart beats by a normal heard rate at rest for adults (70 $min^{-1}$) and dividing by a normal heard rate at rest for the corresponding young patient age population (Fleming et al., 2011).

Table 1. Age correction coefficient in the corrected index formula (Eq.5)

| Years old | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $C$ | 2.7 | 2.9 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 |

The corrected index values (Eq.5) for a six years old patient with a normal HR at rest about 102 bpm equals 5.2, i.e. it is equal to the index value for a "normal" adult calculated with Eq.1. Using Eq.5, we plotted graphs suitable in the practice of physical education and sports medicine because no additional calculations are needed (Fig.1). For example, if a sum of three measured HRs equals 300 bpm (see interrupted lines on Fig.1), corrected index values equal 0.6 for 6 years old patient, 2.6 − 8, 5.0 − 10, 7.1 − 12, 8.4 − 14, and 10.0 for 17 years old patient. The last magnitude of 10.0 is equal to the magnitude calculated with Eq.1.

Approbation of the method of the age-corrected Ruffier index model adapted for children (Eq.5) was carried out in groups of patients 6, 7, 8, and 18–20 years old with 30 subjects in each of them. A statistically significant difference between resting heart rate in the groups of adults and children of 6, 7, and 8 years old was shown ($p < 0.001$). According to the results of one-way analysis of variance of the two-dimensional array of data, a statistically significant difference between the values of the Ruffier index (in its classical form) is revealed in the age classes that were inspected. During the correction of the value of the Ruffier index to the age of patient, the mean value of the index on the age classes statistically proved to be equal to the mean value of the index in the group of adult patients ($p = 0.834$). There were no significant differences between the dynamic reaction of a heart on the physical effort regarding to the age of participants ($p = 0.526$).

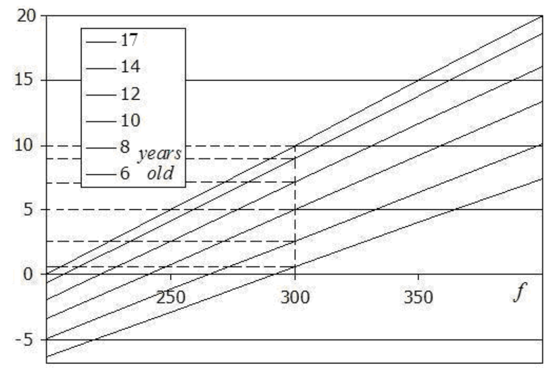


Fig.1. Corrected Ruffier index value vs. sum of HRs: $f = 4(n_0 + n_1 + n_2)$.

We presented another method of Ruffier index adaptation, too. For a classical Ruffier index of resistance of a heart to the physical effort (Eq.1), we prepared a corrected scale of assessment. We derived a formula of corresponding levels as follows:

$$RIB_C = kRIB+20(k-1), \quad \text{(Eq.6)}$$

where $k$ is a ratio of normal heart rate at rest of the patient's age population and adults ($k = 4/C$), $RIB = 3.5, 6.5, 9.5, 14.5$ are the levels for adults. Corrected levels calculated with Eq.6 are collected in Table 2 (Zanevskyy et al., 2022).

Table 2. Corrected levels of Ruffier index

| Years old | Resistance of a heart to the physical effort | | | |
|---|---|---|---|---|
| | excellent | good | average | poor |
| 6 | 14.2 | 18.6 | 23.0 | 30.3 |
| 7 | 12.9 | 17.1 | 21.3 | 28.3 |
| 8 | 11.2 | 15.2 | 19.2 | 25.8 |
| 9 | 9.5 | 13.3 | 17.1 | 23.4 |
| 10 | 8.2 | 11.8 | 15.4 | 21.4 |
| 11 | 6.9 | 10.3 | 13.7 | 19.4 |
| 12 | 6.0 | 9.3 | 12.7 | 18.2 |
| 13 | 5.2 | 8.4 | 11.6 | 17.0 |
| 14 | 4.8 | 8.0 | 11.2 | 16.5 |
| 15 | 4.3 | 7.4 | 10.6 | 15.7 |
| 16 | 3.9 | 7.0 | 10.0 | 15.1 |
| 17 | 3.5 | 6.5 | 9.5 | 14.5 |

So, we have solved a problem of adaptation of Ruffier index to testing of resistance of a heart to the physical effort in childhood and adolescence. We proposed an integrated hypothesis that explains increased values of the index calculated using the original formula (Eq.1). We prepared two methods of adaptation of the index to young patients: a corrected formula of Ruffier index (Eq.5) and a corrected scale of assessment (Eq.6). A novelty of corresponding models is a correction coefficient as a ratio of normal HRs at rest of the young patient and adults. The nomogram shows a correlation between values of the Ruffier index boundaries between the health levels (Fig.2). Using the nomogram, one can determine boundaries' values between the levels of health from the lowest to the highest. For example, when a patient is 10 years old, draw a vertical with the abscissa 10 (interrupted line). In the points of crossing with nomogram lines (continuous), follow horizontal lines (interrupted) to crossing with ordinate and read the boundaries' values. A nomogram showed clearly a decrease of boundaries' values vs. an increase of the patient's age (Zanevskyy et al., 2020; Zanevskyy et al., 2021).

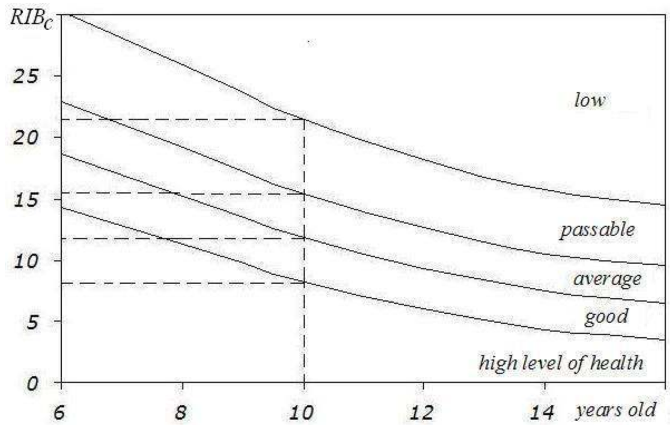


Fig.2. Nomogram of the Ruffier index corrected boundaries' between the levels of health.

*Generalized Dickson index*

We prepared a similar method of the Dickson Index correction, too. Presenting the original Dickson index formula in the shape

$$DI = \frac{4[n_1 + 2(n_2 - n_0)]}{10} - 7\,, \qquad \text{(Eq.7)}$$

and following the idea of transition from the original Ruffier index formula (Eq.1) to the age-generalized formula (Eq.5), we replaced number four in the formula (Eq.7) with parameter $C$ (see Table 1). As a result, the age-generalized Dickson index formula has been derived as follows:

$$DI_C = \frac{C[n_1 + 2(n_2 - n_0)]}{10} - 7\,. \qquad \text{(Eq.8)}$$

Like the age-generalized Ruffier index (see Fig.1), the age-generalized Dickson index was presented in the graph (Fig.3)

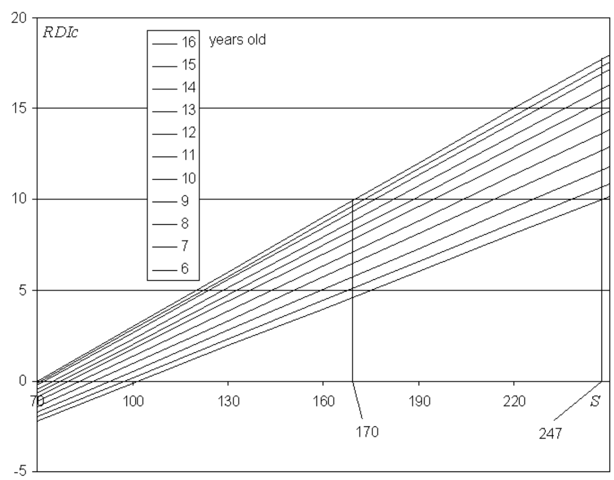


Fig.3. Dickson Index vs. test results regarding patient's age:
$S = P_1 + 2(P_2 - P_0)$, where $P_0 = 4n_0$, $P_1 = 4n_1$, $P_2 = 4n_2$.

With the same heart rate, the index is smaller when a patient is younger. For example, when $S$ = 170, a sixteen years old patient gets $DI_C$ = 10 and a six years old – $DI_C$ = 4.7. When $S$ =247, a sixteen years old patient gets $DI_C$ < 10, that is equal to a passable physical capacity, but a sixteen years old – $DI_C$ = 17.7 – very bad.

We recommend in the practice of physical education to use the original formula of Dickson index (Eq.7) and age-corrected borders between levels of physical capacity:

$$DIB_C = kDIB + 7(k-1), \qquad \text{(Eq.9)}$$

where $DIB_C$ = 0, 2, 4, 6, 8, 10 are boundaries of levels of physical capacity as 'excellent', very good', 'good', 'average', 'passable', 'bad', and 'very bad' correspondingly (Zanevskyy et al., 2023). Calculated with Eq.9 data are collected in Table 3.

Table 3. Age correction of the Dickson index scale

| Years old | Boarders of the Dickson index values between the levels of the physical capacity | | | | | |
|---|---|---|---|---|---|---|
| | 1 – 2* | 2 – 3 | 3 – 4 | 4 – 5 | 5 – 6 | 6 – 7 |
| 6 | 3.2 | 6.1 | 9.0 | 11.9 | 14.9 | 17.8 |
| 7 | 2.8 | 5.6 | 8.4 | 11.2 | 14.0 | 16.8 |
| 8 | 2.3 | 5.0 | 7.6 | 10.3 | 12.9 | 15.6 |
| 9 | 1.8 | 4.3 | 6.8 | 9.3 | 11.9 | 14.4 |
| 10 | 1.4 | 3.8 | 6.2 | 8.6 | 11.0 | 13.4 |
| 11 | 1.0 | 3.3 | 5.6 | 7.9 | 10.1 | 12.4 |
| 12 | 0.8 | 3.0 | 5.2 | 7.4 | 9.6 | 11.8 |
| 13 | 0.5 | 2.6 | 4.8 | 6.9 | 9.1 | 11.2 |
| 14 | 0.3 | 2.3 | 4.4 | 6.5 | 8.5 | 10.6 |
| 15 | 0.1 | 2.2 | 4.2 | 6.2 | 8.3 | 10.3 |
| 16 | 0.0 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 |

* Physical capacity levels: 1 – excellent, 2 – very good, 3 – good, 4 – average, 5 – passable, 6 – bad, 7 – very bad.

For a flash estimation of the boundary values the graph could be suitable (Fig.4).

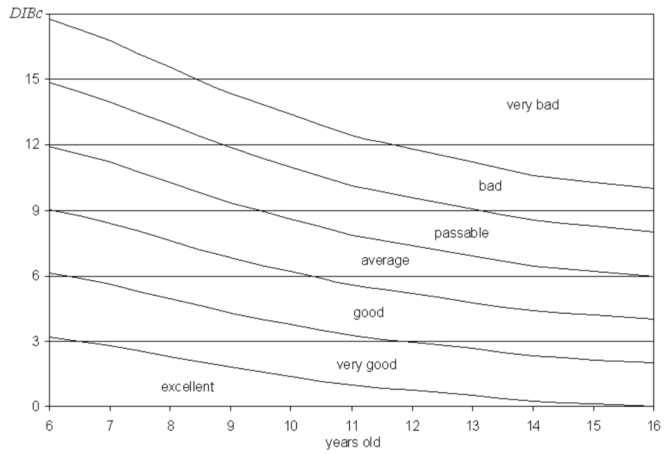


Fig.4. Physical capacity levels relatively Dickson index.

The Ruffier index is more sensitive to variation of a pulse rate than the Dickson index (Fig.5). The range of common values of the Ruffier index is approximately 24 (2 − 26) and the Dickson index − 15 (5 − 20) (Zanevskyy et al., 2018; Zanevskyy et al., 2019).

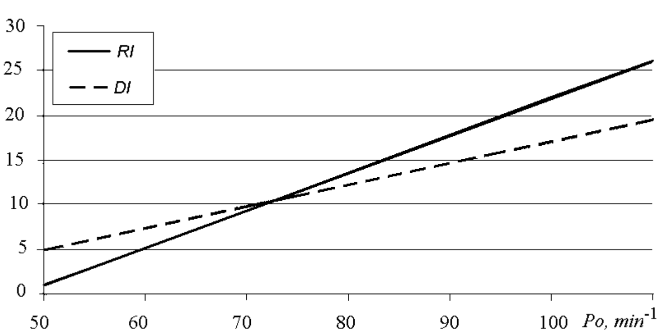


Fig.5. Ruffier (*RI*) and Dickson (*DI*) indexes when $P_1 = 2P_0$, $P_2 = 1.2P_0$.

**Conclusions**

The Ruffier – Dickson squat test with corresponding age-generalized indexes is recommended as a suitable protocol to provide an easy and fast self-evaluation of the maximal oxygen uptake in children and adolescents as well, as in adults. Results presented in graphical and table forms are simple for coachers and physical education teachers, which are not ready for using mathematical models of the Ruffier – Dickson indexes.

It was shown that two well-known models of correction of Ruffier test to the age of young patients are conflicting one to another and are not reliable in physical fitness. Two methods of adaptation of Ruffier test assessment for the health status of young patients were proposed. In one of the methods, a value of Ruffier index was corrected and in another method a scale of assessment was. In general, the proposed model of correction of the test assessment coursed a statistically significant ($p<0.001$) difference with a corresponding result determined according to the original model. The results of this correction showed a considerable increase of a basic group of physical education (in 49-53%) and decrease of a preparation course group (in 11-15%) and a special group (in 37-39%).

A normal value of the heart rate in rest should be used as a parameter of correction of Ruffier index. A corrected value of Ruffier index in the practice of physical education could be calculated using a proposed age correction coefficient.

**Conflict of interest**. Authors declare no conflict of interest regarding this paper.

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