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Reference equations for parameters of impulse oscillometry in Egyptian children and adolescents

Sally Raafat Ishak^{1*}  and Azza Mohammed Hassan²

Abstract

Background: Impulse oscillometry (IOS) is important in diagnosing respiratory functions in non-cooperative children. Studies are rising nowadays to establish reliable reference values of IOS for children of different ethnicities. No available data about the regression equations for parameters of IOS for Egyptian children and adolescents. So, our study aimed to develop regression equations for parameters of IOS in Egyptian children and adolescents in relation to their age, weight, height, and body mass index.

Results: Height and age affected the regression equation of impedance at 5 Hz (Z5 Hz) and resistance at 5 Hz (R5 Hz) in both males and females, resistance at 20 Hz (R20 Hz) in males and reactance at 5 Hz (X5 Hz) in females. Height affected the regression equation of R20 Hz in females, resonant frequency (Fres) in males, and the area of reactance (AX) in both males and females. While age affected the equation of X5 Hz in males and Fres in males.

Conclusions: Height and age were the most predictive values affecting the regression equation of IOS in Egyptian children and adolescents.

Keywords: Reference equation, Egypt, Impulse oscillometry, Pulmonary functions

Background

Pulmonary function tests are important tools in the diagnosis and follow-up of different respiratory diseases especially chronic lung diseases [1].

The impulse oscillometry system (IOS) is important in the diagnosis of respiratory functions in non-cooperative children [2]. It does not depend on the effort of the patients as it needs only tidal breathing, then the sound waves emitted by the apparatus are superimposed on normal tidal breathing, and the disturbances in the flow and pressure (caused by the external waves done by the patients) are used to calculate the resistance to airflow and the reactive parameters over a wide range of frequencies (usually from 5 to 20 Hz). Both the airway resistance and reactance determines the impedance [3, 4].

The best results of IOS done by the patients are usually compared to the predictive reference value of the same sex, age, weight, height, body mass index (BMI) of the patients. These reference values are different for children of different ethnicities; therefore, studies aim to develop local reference values [5]. Studies are increasing nowadays in different populations to increase the use of IOS and its reliability especially in non-cooperative children because till now spirometry is used more reliably as it is more studied [6].

No available predicted values of IOS for Egyptian children and adolescents. The purpose of this study was to get a reliable regression equation for Z5 Hz, R5 Hz, R20 Hz, X5 Hz, Fres, and AX according to age, sex, weight, and height for Egyptian children and adolescents.

* Correspondence: Sally.raafat@med.asu.edu.eg

¹Pediatric Department, Faculty of Medicine, Ain Shams University, Cairo 11865, Egypt

Full list of author information is available at the end of the article



Fig. 1 VIASYS Healthcare GmbH. Leibnizstrasse 7, spirometry and impulse oscillometry

Methods

One hundred thirteen children were able to perform the maneuver properly to get reliable results. They were 65 males and 48 females, their age ranging from 3 to 18 years with a mean of 9.97 ± 4.21 years.

Table 1 Description of anthropometric characteristics and parameters of IOS of studied patients ($n = 113$)

	Minimum	Maximum	Mean	SD
Weight (kg)	12.00	62.00	26.62	12.18
Height (cm)	64.00	168.00	120.92	19.88
BMI (kg/m²)	11.60	27.2	17.25	3.38
Fres (Kpascal)	4.50	32.70	21.47	5.23
AX (Kpascal)	0.17	6.63	2.42	1.40
R5 Hz (Kpascal)	0.24	1.37	0.80	0.25
R20 Hz (Kpascal)	0.24	1.01	0.56	0.18
X5 Hz (Kpascal)	- 0.71	0.34	- 0.30	0.15
Z5 Hz (Kpascal)	0.28	1.51	0.86	0.27

Z5 Hz impedance at 5 Hz, R5Hz resistance at 5 Hz, R20 Hz resistance at 20 Hz, X5 Hz reactance at 5 Hz, Fres resonant frequency, AX area of reactance

Table 2 Comparison between boys and girls regarding age, anthropometric measures, and IOS parameters

	Boys		Girls		t ^a	P value
	Mean	SD	Mean	SD		
Age (years)	10.49	4.31	9.27	4.00	1.535	0.128
Weight (kg)	27.02	11.23	26.08	13.47	0.400	0.690
Height (cm)	122.78	19.95	118.40	19.71	1.162	0.248
BMI (kg/m²)	19.62	17.78	17.87	5.05	0.663	0.509
Fres (Kpascal)	21.23	4.51	21.79	6.11	0.555	0.580
AX (Kpascal)	2.24	1.26	2.66	1.54	1.612	0.110
R5 Hz (Kpascal)	0.76	0.24	0.84	0.25	1.662	0.099
R20 Hz (Kpascal)	0.53	0.16	0.60	0.19	1.975	0.051
X5 Hz (Kpascal)	- 0.28	0.16	- 0.34	0.14	2.175	0.032 †
Z5 Hz (Kpascal)	0.82	0.27	0.91	0.28	1.800	0.075

^aStudent's t test

[†]P value is significant at 0.05 level

Exclusion criteria: any patient with acute or chronic chest disease, on recent or previous respiratory medication, allergic rhinitis or acute and chronic rhinosinusitis, obese children; or children with neurological or muscular diseases.

Sample size justification

Using G power software for sample size calculation, using the F test for linear multiple regression, fixed model, R² deviation from zero.

Setting alpha error at 0.05, power at 0.95, medium effect size (0.15) for regression equation with two predictors, a sample size of at least 110 persons are needed.

Data of the patients were collected as age, sex, weight, height, and body mass index (BMI).

Table 3 Correlation between IOS parameters and both age and anthropometric measures among boys

		Age (years)	Weight (kg)	Height (cm)	BMI (kg/m ²)
Fres	r ^a	- 0.502	- 0.252	- 0.214	0.007
	P value	< 0.001 ‡	0.043 †	0.087	0.955
AX	r	- 0.709	- 0.478	- 0.583	0.030
	P value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.815
R5 Hz	r	- 0.671	- 0.565	- 0.678	0.023
	P value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.854
R20 Hz	r	- 0.573	- 0.551	- 0.613	0.018
	P value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.887
X5 Hz	r	0.632	0.490	0.563	- 0.091
	P value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.472
Z5 Hz	r	- 0.702	- 0.593	- 0.700	0.036
	P value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.777

^aPearson's correlation coefficient

[†]Significant at 0.05 level

[‡]Highly significant at 0.01 level

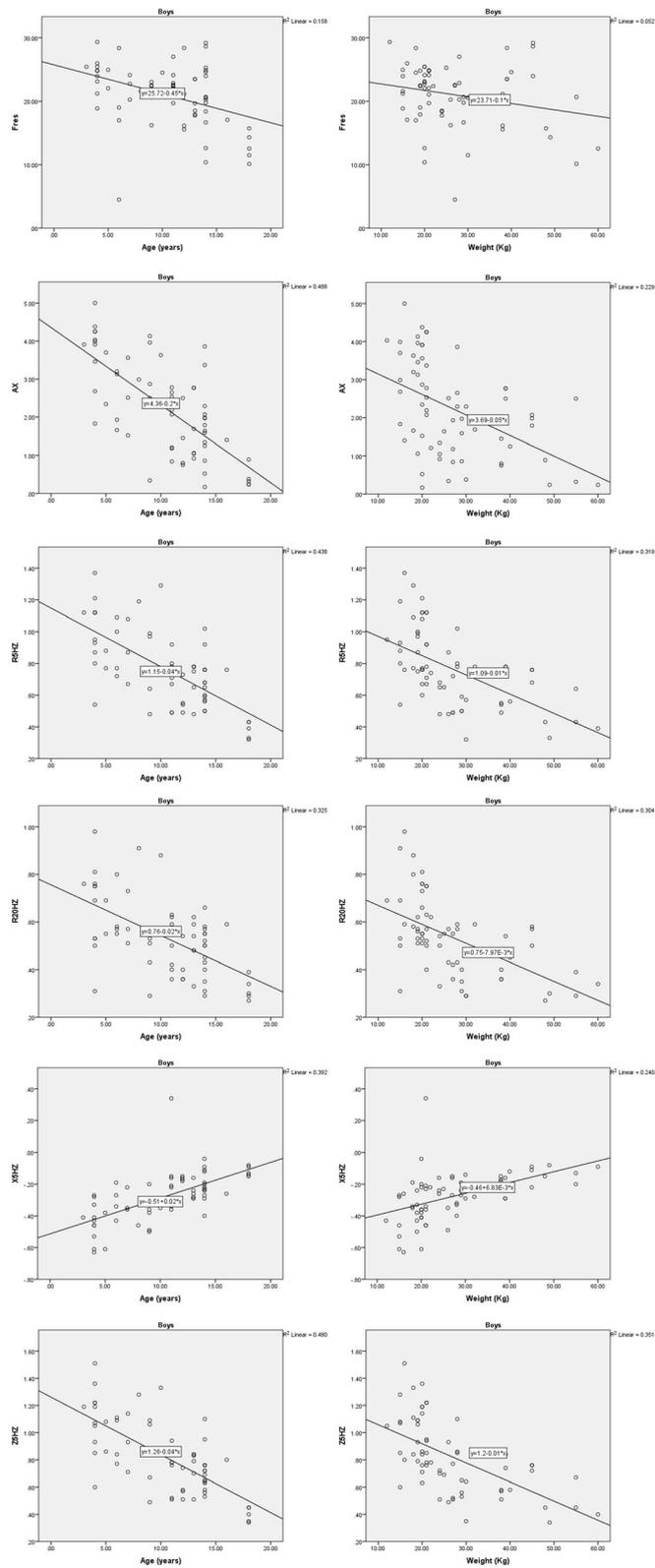


Fig. 2 Regression curve for weight and age in males

Table 4 Correlation between IOS parameters and both age and anthropometric measures among girls

		Age (years)	Weight (kg)	Height (cm)	BMI (kg/m ²)
Fres	<i>r</i> ^a	-0.284	-0.391	-0.372	-0.175
	<i>P</i> value	0.050†	0.006 ‡	0.009 ‡	0.233
AX	<i>r</i>	-0.501	-0.474	-0.525	-0.108
	<i>P</i> value	< 0.001 ‡	0.001 ‡	< 0.001 ‡	0.465
R5 Hz	<i>r</i>	-0.584	-0.621	-0.658	-0.236
	<i>P</i> value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.106
R20 Hz	<i>r</i>	-0.457	-0.516	-0.467	-0.307
	<i>P</i> value	0.001 ‡	< 0.001 ‡	0.001 ‡	0.034†
X5 Hz	<i>r</i>	0.591	0.590	0.620	0.147
	<i>P</i> value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.318
Z5 Hz	<i>r</i>	-0.603	-0.638	-0.676	-0.225
	<i>P</i> value	< 0.001 ‡	< 0.001 ‡	< 0.001 ‡	0.124

^aPearson's correlation coefficient

†Significant at 0.05 level

‡Significant at 0.01 level

The impulse oscillometry procedure was done by all children using VIASYS Healthcare GmbH, Leibnizstrasse 7, Jaegggar, Germany (Fig. 1), according to the American Thoracic Society and European Respiratory Society (ATS/ERS) recommendations [7]:

1. We calibrate the apparatus.
2. Insert patient personal data (name, sex, birth date, weight, and height).
3. Steps were explained to the child for the best performance of the test.
4. The child was asked to sit down in a comfortable chair.
5. A nasal clip was applied to the patient who was asked to mouth breath through a sterile mouthpiece that was grasped tightly by his/her lips and the tongue did not occlude it.
6. On switching on IOS, a small loudspeaker creates a pulse-shaped pressure wave in front of the mouth, with alternate pulses (at different cycles per second [i.e., 5 Hz, 10 Hz, 20 Hz, 25 Hz]).
7. The patient was asked to take tidal breathing with his cheeks supported by the hands of the investigator or the caregiver.
8. Z5 Hz, R5 Hz, R20 Hz, X5 Hz, Fres, and AX were calculated by the software of the apparatus.

Each patient performed 3 trials with less than 10% variabilities. The time of the regular breathing pattern was 90 s. The impedance-time curve was monitored during the measurement to detect possible signs of artifacts.

Accepted patients did the technique properly, with coherence at least 0.8 at 5 Hz and 0.9 at 20 Hz

The study was approved by the local ethics committee of Children's Hospital, Faculty of Medicine, Ain Shams University.

Written consent was taken from the caregiver of the children and adolescents who participated in the study.

Statistical analysis

Analysis of data was done using SPSS program version 23. Quantitative variables are presented as mean and SD, qualitative variables presented as count and percentage. The Student *t* test was used to compare different quantitative variables between boys and girls. Pearson's correlation was used to measure the correlation between IOS parameters and other variables.

Multivariate models were developed by multiple linear regression, incorporating predictor variables correlated to the dependent variable. To choose the best model, the coefficient of determination (adjusted *R*²) was used. The significance level was set at 5% (*P* value < 0.05); and highly significant at 1% (*P* value < 0.01).

Results

From a total of 113 children who participated in the study, 65 were boys (57.5%) and 48 were girls (42.5%). Their age ranged from 3 to 18 years with a mean of 9.97 ± 4.21 years. Table 1 shows the description of their anthropometric measures and IOS parameters. No significant difference was found between boys and girls regarding age, anthropometric measures, and IOS parameters except for R20 Hz, X5 Hz, and Z5 Hz (*P* value ≤ 0.05) (Table 2).

Table 3 and Fig. 2 shows a correlation between different IOS parameters and both age and anthropometric measures among studied boys. There was a statistically significant negative correlation between all IOS parameters and both age and weight except for X5Hz where the correlation was positive (*P* value < 0.05). There was also a statistically significant negative correlation between IOS parameters (AX, R5 Hz, R20 Hz, and Z5 Hz) and height and a significant positive correlation between X5 Hz and height (*P* value < 0.05).

Regarding the correlation between different IOS parameters and both age and anthropometric measures among girls, (Table 4 and Fig. 3) shows that there was a statistically significant negative correlation between all IOS parameters and both age and weight except for X5 Hz where the correlation was positive (*P* value < 0.05). There was also a statistically significant negative correlation between all IOS parameters and height and a significant positive correlation between X5 Hz and height (*P* value < 0.05). A significant negative correlation was found also between R20 Hz and BMI (*P* value < 0.05).

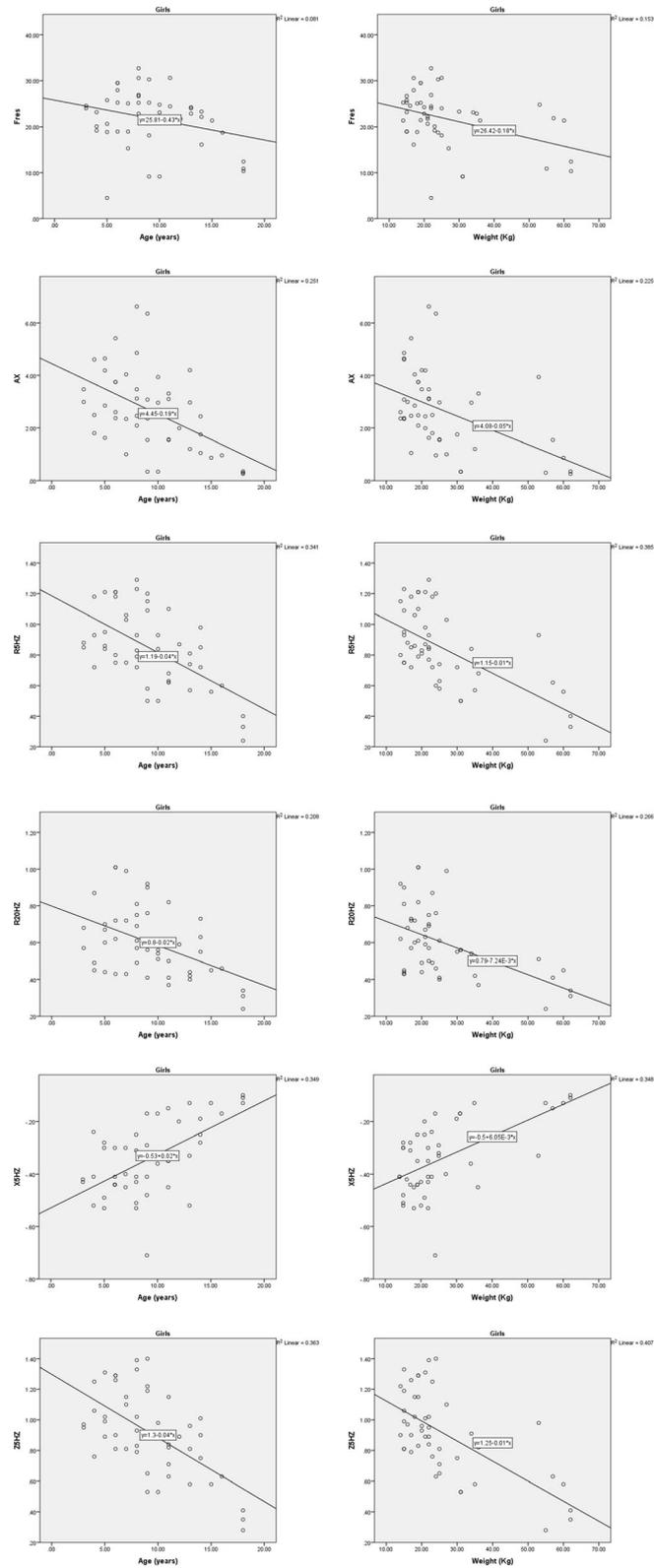


Fig. 3 Regression curves for weight and age for females

Table 5 Respiratory system reference equations obtained by the impulse oscillometry system for boys and girls

IOS parameters	Equations	R ² ,%	Adjusted R ²	SEE
<i>Boys:</i>				
Fres	= 26.742–(0.525 × age)	25.2	24	3.928
AX	= 6.778 – (0.037 × height)	34	33	1.035
R5 Hz	= 1.596 – (0.021 × age) – (0.005 × height)	53.2	51.7	0.168
R20 Hz	= 1.059–(0.010 × age) – (0.003 × height)	41.4	39.5	0.126
X5 Hz	= – 0.520 + (0.023 × age)	39.9	39	0.122
Z5 Hz	= 1.754 – (0.025 × age) – (0.005 × height)	57.5	56.1	0.176
<i>Girls:</i>				
Fres	= 35.454 – (0.115 × height)	13.9	12	5.731
AX	= 7.517 – (0.041 × height)	27.5	26	1.325
R5 Hz	= 1.751 – (0.019 × age) – (0.006 × height)	49.2	47	0.184
R20 Hz	= 1.128 – (0.004 × height)	21.8	20.1	0.169
X5 Hz	= – 0.796 + (0.012 × age) + (0.003 × height)	46.2	43.9	0.103
Z5 Hz	= 1.928 – (0.022 × age) – (0.007 × height)	52.1	50	0.195

Table 5 shows the results of multiple linear regression equations for all IOS parameters in boys and girls with their coefficients of determination (R^2) adjusted R^2 and standard error of the estimate (SEE). Height was the variable with the most predictive power for models of all IOS parameters in girls and most of the parameters in boys.

Discussion

In our study, we found that in Z5 Hz and R5 Hz, height and age affected the prediction equation for both males and females, while in R20 Hz, height and age affected the equation of males; but only the height affected that for females. Concerning the prediction equation for X5 Hz, age was the variable most affecting the equation in males, while height and age affected the equation in females. Height was the variable that has been shown to influence Fres in females and AX in both males and females, but the age was the variable that affected the equation of Fres in males.

So most of the predictive equations for impulse oscillometry were affected by height or age or both of them but none of the equations were affected by weight or BMI, possibly because of the association of height and age with a linear increase in lung volumes.

Comparing these with the study done on Brazilian children, height was found to be the highest predictive variable in the equations for boys in all parameters of IOS, while age had a greater influence on Fres and AX for girls [8]. Also, in a study on Mexican children and adolescents, height was the most variable influencing the equation but age also influenced the regression equation of many IOS variables, whereas body weight did not influence any regression equation; thus, reference values were made

considering age and height [9]. Also, Amra et al. 2018 concluded that both height and age influenced the equation of the Iranian population [10]. While in a study on North American children, height was the only significant predictor for all variables [11].

In Poland and Swedish children, the height⁻³ was the most variable affecting the different oscillometric variables. But the introduction of weight helped to improve the coefficient of determination of some IOS parameters, while, factors as gender, age, and body surface area did not influence the IOS variables. Therefore, height⁻³ and weight were used in the regression equations done for both sex [12].

Also, studies from different ethnicities as Anglo and Hispania [13], Brazil [14], northeast Poland [15], and Taiwan [2], all showed reliability of the regression equations on the height of the children. (Table 6)

Nevertheless, both height and age affected the prediction equations of Korean and Mexican patients, although that for the Korean girls were affected by the height only [5, 9].

Meraz et al. 2007, de Assumpção et al. 2016, Frei et al. 2005, and Dencker et al. 2006 showed no statistically significant difference between both genders in the predictive equations [11–13, 8]. While Amra et al. 2007 found a statistically significant difference between genders [10]. But in our study, no significant difference was found between boys and girls regarding IOS parameters except for R20 Hz, X5 Hz, and Z5 Hz.

Comparing our study on the pediatric age group with other studies in adults, Kalchiem-Dekel and Stella E. Hines studied forty years of reference values for respiratory system impedance in adults from the years 1977–2017 and concluded that most of the prediction equations were from Europe ($n = 20$) and

Table 6 Summary of the predictive equation of impulse oscillometry in different ethnicities

Author, year	Ethnicity	Predictive equation	R ²	Predictive variables
de Assumpção et al. 2016	Brazilian	Boys		Height and age
		R5 Hz = 1.699 – (0.008 × height)	62	
		R20 Hz = 1.226 – (0.005 × height)	49	
		X5 Hz = – 0.552 + (0.003 × height)	15.9	
		Z5 Hz = 1.802 – (0.010 × height)	51	
		Fres Hz = 44.473 – (0.195 × height)	50.5	
		Log AX = 0.332 – (0.002 × height)	58	
		Girls		
		Log R5 Hz = 0.639 – (0.006 × height)	57.5	
		Log R20 Hz = 0.378 – (0.005 × height)	59.1	
		X5 Hz = – 0.586 + (0.003 × height)	55.1	
		Log Z5 Hz = 0.679 – (0.007 × height)	59.9	
		Log Fres = 1.555 – (0.037 × age)	41.1	
		Log AX = 0.892 – (0.106 × age)	49.7	
Park et al. 2011	Korean	Boys		Boys
		R5 Hz = 1.934 – 0.009 × Height	12.1	Height and age
		X5 Hz = 0.774 + 0.006 × Height – 0.002 × Age	20.2	
		Girls		Girls
		R5 Hz = 2.201 – 0.012 × Height	18.2	Height only
		X5 Hz = – 0.674 + 0.004 × Height	10.5	
Denker et al. 2006	Finland and Sweden	Z5 Hz = 0.282 + 0.801 × height ⁻³ + 0.004 × weight		height ⁻³ and weight
		R5 Hz = 0.266 + 0.759 × height ⁻³ + 0.004 × weight		
		R20 Hz = 0.259 + 0.630 × height ⁻³		
		X5 Hz = – 0.123 – 0.225 × height ⁻³		
		Fres = 11.749 + 4.373 × height ⁻³ + 0.103 × weight		
Gochicoa-Rangel et al. 2015	Mexican	Z5 Hz = – 0.595 × log age + 130.320 × 1/height + 0.214		Height and age
		R5 Hz = – 0.736 × log age + 78.861 × 1/height + 0.702		
		R20 Hz = – 0.427 × log age + 69.880 × 1/height + 0.307		
		X5 Hz = 0.309 × log age – 42.906 × 1/height – 0.185		
		Fres = – 0.308 × log age + 2542.196 × 1/height + 0.791		
		AX = – 2.345 × log age + 640.548 × 1/height – 1.212		
Amra et al. 2007	Iranian	Boys		Height and age
		R5 Hz = – 6.19 × 10(– 7) × age × 3.820 – 6.78E–005 × height × 1.651 + 0.691		
		X5 Hz = 6.95 × 10(– 23) × age × 16.226 + 0.004 × height × 0.846 – 0.430		
		Girls		
		R5 Hz = – 1.35 × 10(– 5) × age × 2.823 – 0.001 × height × 1.022 + 0.547		
		X5 Hz = 1.78 × 10(– 7) × age × 1.08 + 0.002 × height × 4.150 – 0.539		
Meraz et al. 2007	Anglo and Hispanic	R5 Hz = 1.428 – 0.006 × height	0.647	Height

Table 6 Summary of the predictive equation of impulse oscillometry in different ethnicities (*Continued*)

Author, year	Ethnicity	Predictive equation	R ²	Predictive variables
Lai et al. 2015	Taiwanese	R20 Hz = 1.072 – 0.005 × height	0.473	Height
		X5 Hz = – 0.340 + 0.001 × height	0.151	
		Fres = 27.589 – 0.008 × height	0.165	
		AX = 1.213 – 0.005 × height	0.241	
		R5 Hz = 2.4395 – 0.0134 × height		
		R20 Hz = 1.3888 – 0.0069 × height		
Frei et al. 2005	North American	X5 Hz = – 0.6408 + 0.0036 × height		Height
		AX = 10.4286 – 0.0686 × height		
		R5 Hz = 2.11679 – 0.0099 × height	0.435	
		R20 Hz = 1.45644 – 0.0065 × height	0.321	
		X5 Hz = – 1.1974 + 0.00673 × height	0.219	
		AX = 10.9448 – 0.684 × height	0.351	

Z5 Hz impedance at 5 Hz, R5 Hz resistance at 5 Hz, R20 Hz resistance at 20 Hz, X5 Hz reactance at 5 Hz, Fres resonant frequency, AX area of reactance

Asia ($n = 12$) while studies in Africa are limited; and across publications, height and sex were major contributors to prediction equations. The contribution of weight was more pronounced in obese patients only. The contribution of age was less clear, and the elderly were largely under-represented. Ethnicity likely plays a role but was under-reported in currently available publications [3, 16].

The study on adults done by Schulz et al. showed that R5 Hz was higher in females than males while X5 Hz was higher in males than females. Some of the IOS equations were age-dependent. Also, studies by Aarli et al. and Newbury et al. found that airway resistance is greater in women than in men during adulthood [17, 18].

By comparing R^2 of our study to that in the studies done on different ethnicities, we found that our R^2 is higher than that in the equations of Korean, Angelo, Hispanic, and North American studies. While it was lower than R^2 of the Brazilian study except for the predictive equation for X5 Hz for boys where our R^2 was higher (Tables 5 and 6).

This study has a potential limitation that it did not include the population from different cities in Egypt. Further studies are needed to develop reference equations for parameters of IOS on a wider scale and larger sample sizes that can be applied to all Egyptian children and adolescents in different cities.

Conclusion

Both height and age affected the regression equation for parameters of impulse oscillometry in Egyptian children.

Abbreviations

AX: Area of reactance; Fres: Resonant frequency; IOS: Impulse oscillometry; R5 Hz: Resistance at 5 Hz; R20 Hz: Resistance at 20 Hz; X5 Hz: Reactance at 5 Hz; Z5 Hz: Impedance at 5 Hz

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Authors' contributions

SI conceived the presented idea, carried out the impulse oscillometry for the subjects, collected the data, and wrote the manuscript, while AH analyzed the data and developed the equations. Both authors have read and approved the manuscript.

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Availability of data and materials

Data and materials are available upon request.

Ethics approval and consent to participate

Approval of the medical ethical committee of Children's Hospital, Ain Shams University, was taken before the study. The committee's reference number is not available. Written informed consent was obtained from a parent or legal guardian of participants under 16 years old.

Consent for publication

Not applicable

Competing interests

No conflict of interest.

Author details

¹Pediatric Department, Faculty of Medicine, Ain Shams University, Cairo 11865, Egypt. ²Community, Environmental and Occupational Medicine Department, Faculty of Medicine, Ain Shams University, Cairo 11865, Egypt.

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