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Normal values of respiratory oscillometry in South African children and adolescents

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Abstract

Introduction:

Non-invasive measurement of respiratory impedance by oscillometry can be used in young children from 3 years and those unable to perform forced respiratory manoeuvres. It can discriminate between healthy children and those with respiratory disease. However, its clinical application is limited by the lack of reference data for African paediatric populations.

Aim:

To develop reference equations for oscillometry outcomes in South African children and adolescents.

Methods:

Healthy subjects, enrolled in the Drakenstein Child Health Study, HIV uninfected adolescents in the Cape Town Adolescent Antiretroviral Cohort and healthy children attending surgical outpatient clinics at Red Cross War Memorial Children's Hospital were measured with conventional spectral (6-32 Hz) and intra-breath (10 Hz) oscillometry. Stepwise linear regression was used to assess the relationship between respiratory variables and anthropometric predictors (height, sex, ancestry) to generate reference equations.

Results

A total of 692 subjects, 48.4% female, median age of 5.2 years (range: 3-17 years) were included. The median interquartile range (IQR) for weight for age z-score and height for age z-score was -0.42 (-1.11 ; 0.35) and -0.65 (-1.43 ; 0.35), respectively. Stepwise regression demonstrated that all the variables were significantly dependent on height only. Comparison to previous reference data indicated slightly higher resistance and lower compliance values in the smallest children.

Conclusion

We established the first respiratory oscillometry reference equations for African children and adolescents, which will facilitate use in early identification and management of respiratory disease. Our results suggest differences in oscillometry measures by ancestry but also highlight the lack of standardisation in methodology.

"Take home" message

The first respiratory impedance reference equations for African children and adolescents are established to aid in early identification and diagnosis of respiratory impairment.

Introduction

Measurement of lung function in early childhood is important for the diagnosis and management of lung disease, to promote optimal lung growth and development. Early life lung function predicts later morbidity and mortality.[1, 2] Spirometry is currently the most commonly performed lung function test, but its use is limited in young children as it requires a forced expiratory manoeuvre, mostly only feasible in children ≥5 years of age. In addition, it is relatively insensitive to detect early lung disease and is a poor measure of peripheral airway function.[3]

Oscillometry is an attractive, feasible option in preschool children as it is a simple non-invasive test, requires minimal co-operation and can be used to follow lung function across the life course. Oscillometry measures the response of the respiratory system to an external small-amplitude oscillatory signal of medium (e.g. 4-40 Hz) frequencies which is superimposed on tidal breathing. The oscillatory pressure-flow relationship reflects the mechanical impedance of the respiratory system (Z_{rs}), which consists of two components, namely resistance (R_{rs}) and reactance (X_{rs}).[4, 5]

The conventional multi-frequency or spectral values of Zrs are generally obtained for a number of consecutive whole breaths (or, more recently, as mean values for the inspiratory and expiratory phases). In contrast, the novel intra-breath measurements, collected with a single frequency tracking signal, follow the changes in Rrs and Xrs *within* the breathing cycle.[6] In particular, intra-breath oscillometry focuses on the zero-flow points (end inspiration and expiration); these Zrs values are less influenced by the breathing pattern which is often variable in young children and reflect less from the contribution of the flow-dependent extrapulmonary airways. Due to the ability to measure Rrs and Xrs at specific points of the respiratory cycle and thus estimate the tidal changes in respiratory mechanics intra-breath oscillometry has proved more sensitive than standard measures to assess airway obstruction, ventilation inhomogeneity, asthma control and respiratory disease risk.[7-10]

Accurate interpretation of lung function measurements depends on the availability of a robust reference standard specific to the population assessed. Population differences in lung function such as anthropometric, sociocultural and environmental characteristics are well recognised.[11-13] Most oscillometry reference standards are specific for Caucasian populations from Europe, North America and Australia between the ages of 2 to 16 years.[14-27] Studies of non-Caucasian participants include Mexican, Thai, Emirati, Korean, Taiwanese, Turkish and Indian population groups with an age range between 3 and 17 years.[28-34] While reference equations derived from Caucasian data may be adequate for Caucasian South Africans, the most recent census describes the South African population as multi-ancestry: 80.7 % Black African, 8.8% mixed ancestry (which would include African ancestries, Asian, Caucasian, amongst others) and 2.6% Indian/Asian.[35] Currently, no oscillometry reference equations exist for African populations, despite the high burden of respiratory disease in the region. Additionally, normative data on the novel intra-breath oscillometry measures are scant [8] and are not available for paediatric populations beyond infancy.[9, 36] Recent technical standards for oscillometry equipment and testing, developed by an ERS task force have highlighted the lack of appropriate paediatric reference standards, especially for underrepresented populations.[37]

The aim of this study was to develop reference values for spectral and intra-breath oscillometry measures in healthy South African children and adolescents.

Methods:

Participants

Healthy children and adolescents were enrolled from 3 South African groups: the Drakenstein Child Health Study (DCHS), a birth cohort study [38]; the Cape Town Adolescent Antiretroviral Cohort (CTAAC), including a healthy HIV-uninfected control group [39]; healthy children with no history of respiratory illnesses attending surgical outpatient clinics at Red Cross War Memorial Children's Hospital, Cape Town (HCSOC). Participants from the DCHS birth cohort were tested annually (collected 2015-2020) from 3 to 7 years; with one randomly selected time point per individual included in this study to remove any bias in the sample. Participants from CTAAC (11-15 years) and HCSOC (8-17 years), were tested between 2018-2020. All participants were of African ancestry, self-identifying as either Black African or mixed ancestry and from predominantly low socioeconomic communities. [38, 39] Socioeconomic status was determined from questionnaires completed at study visits and was based on household income, including accessed social grants. Household smoking was self-reported.

All children were healthy at the time of testing. Prior to testing they were screened for respiratory symptoms (cough, wheeze, difficult breathing) using a clinical and symptom study questionnaire based on the validated ISAAC questionnaire. Those with acute lower respiratory tract illness (LRTI) or any respiratory illnesses in the previous month were excluded from testing. LRTI was defined as per the WHO case definition.[40] In addition children with any chronic respiratory conditions (self-reported or doctor diagnosed) including recurrent or persistent wheeze as well as chronic illnesses such as HIV infection, cardiac or neurological disorders were also excluded.

Ethics

The study was approved by the University of Cape Town Faculty of Health Sciences (048/2020; 082/2018; 423/2012). Parents or legal guardians gave written informed consent in their first language and assent was given by all youth 7 years and older.

Lung Function measurements

Oscillometry data were obtained using the same custom made equipment (INCIRCLE wavetube system, University of Szeged, Hungary), [41, 42] by a trained team of three technologists. Measurements were made with the individual sitting comfortably, breathing through a mouthpiece and filter, nose clip in place and the cheeks firmly supported , in accordance with published consensus guidelines.[37] The oscillometry system operated with either a pseudo-random signal in the 6-32 Hz range (conventional oscillometry) or a 10 Hz intra-breath tracking frequency; the latter corresponds to a 0.1-s temporal resolution allowing identification of the zero-flow Zrs values (see below). Measurements consisted of a maximum of five 16 s epochs of multifrequency oscillations to yield a minimum of three acceptable measurements and one 16 s intra-breath recording, repeated if necessary to obtain a minimum of five regular breaths, i.e. without any vocal cord noise, apnoea, irregular breathing pattern, glottic closure, leak or sighs.

Conventional oscillometry measures included R_{rs} at 6 Hz (R_6), 8 Hz (R_8) and 10 Hz (R_{10}), X_{rs} at 6 Hz (X_6), 8 Hz (X_8), 10 Hz (X_{10}), frequency dependence of R_{rs} (R_6-R_{20}), resonance frequency (F_{res}) and the absolute area of the X_{rs} vs frequency plot between 6 Hz and F_{res} (Ax). Additionally, mean respiratory system resistance (R), inertance (I) and compliance (C) were determined from model fitting to the measured Z_{rs} data in the frequency range 10-20 Hz for R and 6-32 Hz for I and C.[41-43] This procedure is illustrated in Fig. S1 of the Supplementary material*.

The intra-breath measurements were characterised by R_{rs} at end inspiration (R_{eI}) and at end expiration (R_{eE}), X_{rs} at end expiration (X_{eE}) and end inspiration (X_{eI}), and their tidal changes R_{eE}-R_{eI} (ΔR) and X_{eE}-X_{eI} (ΔX).

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*In the following, Figures and Tables presented in the Supplementary material will be denoted Fig. S1, S2, … ,Table S1, S2, … , etc.

Statistical Analysis

Data were analysed using STATA 14.1 (STATA Corporation, College Station, TX USA), and presented as frequencies, proportions, median and interquartile range (IQR) as appropriate. A natural logarithmic transformation was used for R, R_6, R_8, R_{10}, C, $F_{res,}$ Ax, $R_{eE,}$ R_{eI}. The effect of sex on oscillometry outcomes was investigated using Wilcoxon Rank-sum test (Mann-Whitney U test), and the relationship between the oscillometry outcomes and anthropometric covariates [sex, height (Ht) and ancestry] were explored using a backward stepwise linear regression. A reference equation for each outcome was generated and presented with the adjusted R^2 and standard error of the estimate (SEE) to allow z-score calculation: z-score = (measured value - predicted value)/SEE.

In order to assess the effect of puberty (particularly as numbers in this age group were relatively low) on the reference equation, backward stepwise regressions with anthropometric data for sex, Ht and ancestry were used to generate a reference equation in children between 3 to 7 years of age from the DCHS cohort.

BIC (Bayesian Information Criteria) models were used to select the best model fit for each of the oscillometry outcomes. In addition, diagnostic checks were done to ensure that the assumptions of linear regression were not violated. This included testing for the presence of multicollinearity using variance inflation factor (VIF), normality of residuals using histograms, kernel density and quantile-quantile plots, and homoscedascity using residual versus fitted plots.

<u>Results</u>

A total of 692 children between the ages of 3 and 17 years were included in the study; 573 (82.8%) were from the DCHS cohort, 38 (5.5%) and 81 (11.7%) from the CTAAC and HCSOC sites, respectively, all representative of the same population group. All were of African ancestry, 361 (52%) were self-identified Black Africans and 331(48%) of mixed ancestry. Demographic details and anthropometry of cohort including the weight for age z-score (WAZ) and Ht for age z-score (HAZ) data are summmarised in Table 1 and detailed in Table S1. A total of 13 children (2%) were severely stunted (≤3 standard deviations below the mean) and 4 children (0.6%) were severely underweight (≤3 standard deviations below the mean). Six children (0.9%) were obese (≥3 standard deviations above the mean). Notably, 29% of mothers self-reported smoking.

The conventional and intra-breath impedance measures are shown for all age groups in Table S2. Values of F_{res} were available (i.e. fell in the 6-32 Hz range) in 514 (74.3 %), less in the youngest and in most of the older children. The R and C data exhibited marked Ht dependences (Fig. 1); the compensatory parameter I has less physiological importance and its values are not reported here. In Fig. 1, regressions on R and C vs. Ht established in earlier work using model fitting are also plotted for comparison. The changes in various Z_{rs} measures with Ht are represented in Figs S2a and b, exhibiting a decrease in R_6 and increase in X_6 with Ht. As shown in Figs S2c, S2d and S2e, F_{res}, Ax and R_6-R_{20} decreased with increasing Ht. The intra-breath measures are plotted against Ht in Fig. S3. ΔR and ΔX exhibited large scatters but were predominantly positive (Figs S3c and S3f, respectively).

Stepwise regression analysis demonstrated the significant association with Ht for all variables; R_6, X_8, X_{eE} and X_{eI} were also found to be associated with sex; X_8 and X_{10} with ancestry. However, as demonstrated by the BIC model (Table S3), these additional associations offered negligible contribution to predictive models. Thus, only Ht was included in all regression models. The reference equations are compiled in Table 2. An online tool using these equations for z-score calculation is available from the link of the Supplementary material.The limits of normal are +1.64 z-score for R values, F_{res}, Ax, $R_{6\text{-}20}$, and -1.64 z-score for X values.

To assess the effect of puberty on the reference range equations, stepwise regression in children from the DCHS cohort was done; the coefficients obtained (Table S4) remained very close to that of the reference equations for the entire cohort, with a moderate decrease in adjusted R^2 attributable to the narrower Ht range. The consistency of reference equations between the full and reduced ranges in Ht is also illustrated in Fig. 1, Figs. S2 and S3. Overall, the deviations between the full and reduced Ht range predictions are significant only in ΔR (Fig. S2), and mild in C (Fig. 1), X_6 and Ax (Fig. S2), R_{eI}, X_{eE} and X_{eI} (Fig. S3). Excellent agreements were found for R and R_6 between the full and reduced Ht range predictions.

The comparison between R_6 predicted with the current equation and other published reference equations for different populations is illustrated in Fig. 2.[14-26, 30, 34] Initially, we considered reference data from previous studies only if (a) Rrs values at around 5-6 Hz were analysed, (b) Ht was the single independent variable and (c) higher-order than linear relationship to Ht was assumed. The main features of these studies are summarised in Table 3. Our R_6 values are similar to the Rrs plots of the other studies at the medium Ht range. Addition of 8 reference data that assumed the linear Rrs *vs* Ht relationship (Table S3) are shown in Fig. S4; these reference lines are rather scattered and fall outside the nonlinear regressions and illustrate the inadequacy of the linear Ht dependence, especially in wide Ht range.

Discussion

This is the first study to report oscillometry data in healthy African children and adolescents and to include both conventional and intra-breath measures. Our findings compare favourably with previously published normative data from other populations; suggesting that standardisation of methodology is a key factor accounting for cohort differences, while indicating the role of population differences.

The vast majority of normative data derived since 1972 includes predominantly Caucasian populations, covering various age ranges and utilises a variety of oscillometry equipment. Additionally, the predictions employed different statistical models and anthropometric variables, further hindering direct comparison. We therefore limited the comparison of the present data to studies that reported Ht as the only independent variable and used a nonlinear Ht dependence of Zrs measures, as appropriate. The inappropriateness of the linear Rrs vs Ht relationship is highlighted in Fig. S4.

To our knowledge, Fig. 2 represents the most comprehensive survey on the Ht dependence of Rrs values in children and adolescents, although the permissive inclusion of the different lowest frequencies (4, 5 or 6 Hz) or frequency ranges for model fitting increases the variability. The roughly inverse relationships between Rrs and Ht exhibit some variability between the normative studies, and our data, which covers one of the widest Ht ranges, is consistent with this (see Fig. 2). We note that some nonlinear models, such as polynomial regressions, may predict unrealistic inflections in the Rrs vs Ht relationships towards lower Ht [27] or higher Ht.[26] Apart from this, in the lowest Ht range (<120 cm), our 6-Hz Rrs values are among the highest, together with lower-frequency (4 and 5 Hz) measurements expected to result in higher Rrs [16, 21], and that obtained with a special (head generator) device[25] leads to higher values than the uncorrected Rrs. A more rigorous comparison covering only Zrs data at 10 Hz is presented in Fig. S5; the relative position of our R_{10} values remains similar to that shown in Fig. 2, whereas our X_{10} data are rather in the middle of the smaller set of available X_{10} predictions. There appears to be a systematic difference between our predictions and those based on the same oscillometry setup employed in a population of Caucasian children.[41] Comparison of Fres vs Ht regressions reveal a wide scatter between studies, in which our data take a midposition.

Ethnic differences in oscillometry measurements obtained with the same device have been noted [28]; ancestry, environmental and body habitus differences which influence Ht, were the most likely suggested reasons accounting for this discrepancy. Moreover, differences in Ht between populations appear to be greatest in preschool years.[44] The fact that our cohort had a higher Rrs at Ht <120 cm possibly indicates that the younger children in our study may have smaller lungs for a given Ht compared to other healthy reference populations. We noted a higher Rrs with a predominantly lower Xrs in oscillometry variables in females compared to males, similar to findings by others.[14, 47] However, we found that sex was not independently predictive after adjusting for Ht. Difference in Zrs between females and males in childhood and adolescence may be primarily driven by smaller lung volumes and narrower airways in females compared to males.[48, 49]

Many early life factors influence lung growth and development, including environmental smoke exposure and socio-economic status (SES).[11, 38] Our study population was from a predominantly low SES community with a high smoke exposure, 29% of mothers in our cohort smoked.[38, 39] However, this subtle difference in Rrs at small Ht should be interpreted with care as measurement accuracy has been shown rather variable between commercial oscillometry devices at high load impedances, such as Zrs in small children.[45] It is worth noting that the reference equipment in this device comparison study [45] was the wave-tube setup [41, 42] employed in the present investigation. Efforts are underway to align and standardise equipment signalling and processing, including the development of consensus guidelines.[37, 41, 45, 46]

In addition to the conventionally reported Rrs and Xrs values at the oscillation frequencies, F_{res} and Ax are increasingly used to determine the elasticity and ventilation inhomogeneity of the respiratory system, whereas R_{6-20} reflects peripheral inhomogeneity and airway obstruction.[45] With the exception of F_{res}, these measures are very sensitive to the value of the lowest oscillation frequency, which is rather variable between devices and hence different studies; this is another argument calling for urgent standardisation effort. We have added the mean Rrs (R) and C parameters from model fitting [42, 43] and propose these measures as more robust descriptors of the resistive and reactive behaviour of the respiratory system than the Rrs and Xrs readings at individual frequencies. Reports on R and C in paediatric populations are scant in the literature[22, 25]; the most important comparison with a previous study [41] that employed the same oscillometry device and evaluation procedure (Fig. 1) reinforces the single-frequency findings on the relatively high resistance and low compliance values in our pre-schooler population.

This study is one of the first to develop comprehensive reference equations for the novel intra-breath oscillometry measurements in the paediatric population.[7-9] Intrabreath measures have been shown to be a measure of airway obstruction in preschool children with wheezing and altered in children with asthma.[7] We have also previously shown that these measurements were able to predict healthy infants at risk for lower respiratory tract infections.[47] The clinical utility of the intra-breath measures together with standardised conventional spectral variables in children need to be fully established and ongoing work is recommended in this area to facilitate diagnosis of respiratory disease with more precision.

Strengths of this study include the large sample of healthy children with data collected using the same equipment and methodology. The age range of children extended from preschool to adolescence provides us with a tool useful through childhood and adolescence. The availability of an online tool for calculation of the lower/upper limits of normal and z-score simplifies this further, facilitating its use for users in the field.

A limitation of this study is the relatively small sample size in the 8 to 17 year age interval, a time of variable lung growth particularly between sexes, thus assessing the impact of puberty was limited. Since there is a remarkable consistency in the Ht dependencies of the major oscillometry measures between the full (3-17 yr) and the lower (3-7 yr) age ranges, these reference equations aim to guide clinical practice until they are updated by using more balanced patient cohorts. In addition, these normative values are based only on data from a single province, the Western Cape, of South Africa, therefore this may not necessarily be generalisable to the rest of the Southern African region, although recent multi-province healthy data collection shows concordance in spirometry measurements.[48]

In conclusion, we have established the first respiratory impedance reference equations for South African children and adolescents with an online tool to facilitate its use in early identification and management of respiratory disease. While our results reveal differences in oscillometry measures by ancestry, they also highlight the lack of standardisation in methodology.

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Tables and Figures

Table 1 : Demographic table of all children and adolescents

Individual Characteristics	n=692
Sex	**n (%)**
Female	335 (48.4)
Age*	5.2 (4.2;7.2)
Site	
CTAAC	38 (5.5)
Healthy Surgical (HCSOC)	81 (12.7)
DCHS	573 (82.8)
Ancestry	
Black African	361 (52.2)
Mixed ancestry	331 (47.8)
Weight (kg)*	18.20 (15.25;23.10)
WAZ*	-0.42 (-1.11;0.35)
Height (cm)*	110 (101;120.)
HAZ*	-0.65 (-1.43;0.05)
BMI (kg/m^2)*	15.50 (14.53;17.04)
BMI-Z*	-0.04 (-0.70; 0.76)
Housing**	
Informal settlement	255/611 (58.3%)
Maternal smoking**	179/611 (29.3)

CTAC: Cape Town Adolescent Antiretroviral Cohort; HCSOC: Healthy Children at surgical outpatient clinics
DCHS: Drakenstein Child Health Study; BMI: Body mass Index; WAZ: weight for age z-score;
HAZ: height for age z-score; BMI-Z: Body mass index z-score
*Median and interquartile range (IQR) reported
**Information not available for HCSOC
[1]: shelter constructed outside of the formal housing delivery system[49]; remainder classified as urban

Table 2: Reference equations for children and adolescents 3 to 17 years of age

Outcome	Equation	Adj R^2	SEE
$\mathbf{R_6}$ (hPa.s.L^{-1})	$\exp(4.34 - 0.0189 \cdot Ht)$	0.723	0.214
$\mathbf{R_8}$ (hPa.s.L^{-1})	$\exp(4.29 - 0.0190 \cdot Ht)$	0.735	0.210
$\mathbf{R_{10}}$ (hPa.s.L^{-1})	$\exp(4.27 - 0.0191 \cdot Ht)$	0.747	0.204
$\mathbf{X_6}$ (hPa.s.L^{-1})	$3.46 - 727 \cdot Ht^{-1}$	0.405	1.168
$\mathbf{X_8}$ (hPa.s.L^{-1})	$3.31 - 647 \cdot Ht^{-1}$	0.425	0 .995
$\mathbf{X_{10}}$ (hPa.s.L^{-1})	$2.73 - 531 \cdot Ht^{-1}$	0.359	0 .938
$\mathbf{F_{res}}$ (Hz)	$\exp(3.74 - 0.0062 \cdot Ht)$	0.230	0.211
$\mathbf{R_6}$-$\mathbf{R_{20}}$ (hPa.s.L^{-1})	$5.67 - 0.0311 \cdot Ht$	0.177	1.227
Ax (hPa.L^{-1})	$\exp(6.35 - 0.0287 \cdot Ht)$	0.416	0.624
R (hPa.s.L^{-1})	$\exp(4.16 - 0.0187 \cdot Ht)$	0.739	0.205
C (L.hPa^{-1})	$\exp(0.099 + 0.0168 \cdot Ht)$	0.523	0.295
$\mathbf{R_{eE}}$ (hPa.s.L^{-1})	$\exp(4.36 - 0.0204 \cdot Ht)$	0.734	0.225
$\mathbf{R_{eI}}$ (hPa.s.L^{-1})	$\exp(4.32 - 0.0208 \cdot Ht)$	0.729	0.233
$\mathbf{X_{eE}}$ (hPa.s.L^{-1})	$2.17 - 409 \cdot Ht^{-1}$	0.174	1.178
$\mathbf{X_{eI}}$ (hPa.s.L^{-1})	$3.22 - 577 \cdot Ht^{-1}$	0.397	0.943
ΔR (hPa.s.L^{-1})	$2.26 - 0.0144 \cdot Ht$	0.040	1.272
ΔX (hPa.s.L^{-1})	$1.80 - 0.0117 \cdot Ht$	0.050	0.928

R_6, R_8 and R_{10}: resistance at 6, 8 and 10 Hz; X_6, X_8 and X_{10}: reactance at 6, 8 and 10 Hz; F_{res}: resonance frequency; R_6-R_{20}: difference between resistance at 6 Hz and resistance at 20 Hz; Ax: area under the reactance curve; R: resistance from model fitting; C: compliance from model fitting; R_{eI}: resistance at end inspiration; R_{eE}: resistance at end expiration; ΔR: R_{eE}-R_{eI} ; X_{eI}: reactance at end inspiration, R_{eE}: reactance at end expiration; ΔX: X_{eE}-X_{eI}. Adj R^2: adjusted R^2; SEE: standard error of the estimate.

Table 3: Summary of reference studies on resistance (R) *vs* height (Ht) relationships*

Author(s) [ref]	year	frequency (Hz)	device	country/race	no. of subjects	age range (yr)	reference equation
Mansell et al. [19]	1972	5	custom made	Canada	79	3-17	$R5=\exp(1.877-0.0089\cdot Ht)$
Cogswell [20]	1973	5-7	custom made	UK	204	3-12	R5-7 *vs* Ht range data
Stanescu et al. [18]	1979	4-9	custom made	Belgium	130	3-14	R4 *vs* Ht range data
Solymar et al. [21]	1985	2-12	custom made	Sweden	218	2-18	$R4=\text{antilog}(1.053-2.18\cdot\log(Ht))$
Hordvik et al. [15]	1985	2-26	Jones Oscillaire	USA/C	138	2-16	$R6=9.2\cdot Ht^2-34.1\cdot Ht+35.2$
Hantos et al. [22]	1985	3-10	custom made	Hungary	121	4-16	$R(3\text{-}10)=1.28\cdot 10^5\cdot Ht^{-2.05}$
Duiverman et al. [26]	1985	2-26	custom made	The Netherlands/C	255	2.3-12.5	$R6=0.0017\cdot Ht^2-0.541\cdot Ht+47.73$
Ducharme et al. [23]	1998	8-16	Custo Vit R	Canada/mixed	199	3-17	$R8=\exp(10.99-2.37\cdot\ln(Ht))$
Mazurek et al. [25]	2000	4-32	custom made	Poland	127	2.5-7.5	$R6=\exp(2.4422-1.7447\cdot\ln(Ht))$
Malmberg et al. [17]	2002	5-35	Jaeger IOS	Finland	109	2-7	$R5=\exp(2.115-1.786\cdot\ln(Ht))$
Dencker et al. [24]	2006	5-35	Jaeger IOS	Finland-Sweden/C	360	2-11	R5 *vs* Ht curve
Nowowiejska et al. [16]	2008	5-35	Jaeger IOS	Poland	626	3-18	$R5=\exp(-0.0169\cdot Ht+1.818)$
Calogero et al. [14]	2013	4-48	Chess i2M	Australia-Italy/C	760	2-13	$R6=\exp(3.3738-0.01155\cdot Ht)$
Shackleton et al. [41]	2018	6-26	custom made**	Australia/Hungary/C	319	3-6	$R6= \exp(3.3501-0.01033\cdot Ht)$
AlBlooshi et al. [30]	2018	5-37	tremoflo C-100	UAE/Emirati	291	4-12	$R5=\exp(3.786-0.014\cdot Ht)$
Er et al. [34]	2019	5-35	Jaeger IOS	Turkey/Turkish	151	3-7	$R5=\text{antilog}(0.527-0.005\cdot Ht)$
Ducharme et al. [27]-1	2022	5-37	Resmon Pro	Canadian/mixed	271	3-17	$R5=\exp(-0.1509+0.00809\cdot Ht-0.0000824\cdot Ht^2)$
Ducharme et al. [27]-2	2022	5-37	tremoflo C-100	Canadian/mixed	292	3-17	$R5=\exp(-0.0252+0.00809\cdot Ht-0.0000817\cdot Ht^2)$

C: Caucasian (when stated). Units in the reference equations are as originally reported: R in $cmH_2O.s.L^{-1}$, $hPa.s.L^{-1}$ or $kPa.s.L^{-1}$; Ht in cm or m.
*Only studies that used nonlinear formulae are included; those assuming linear relationship are added in Table S5.
**Identical device to that used in the present study.

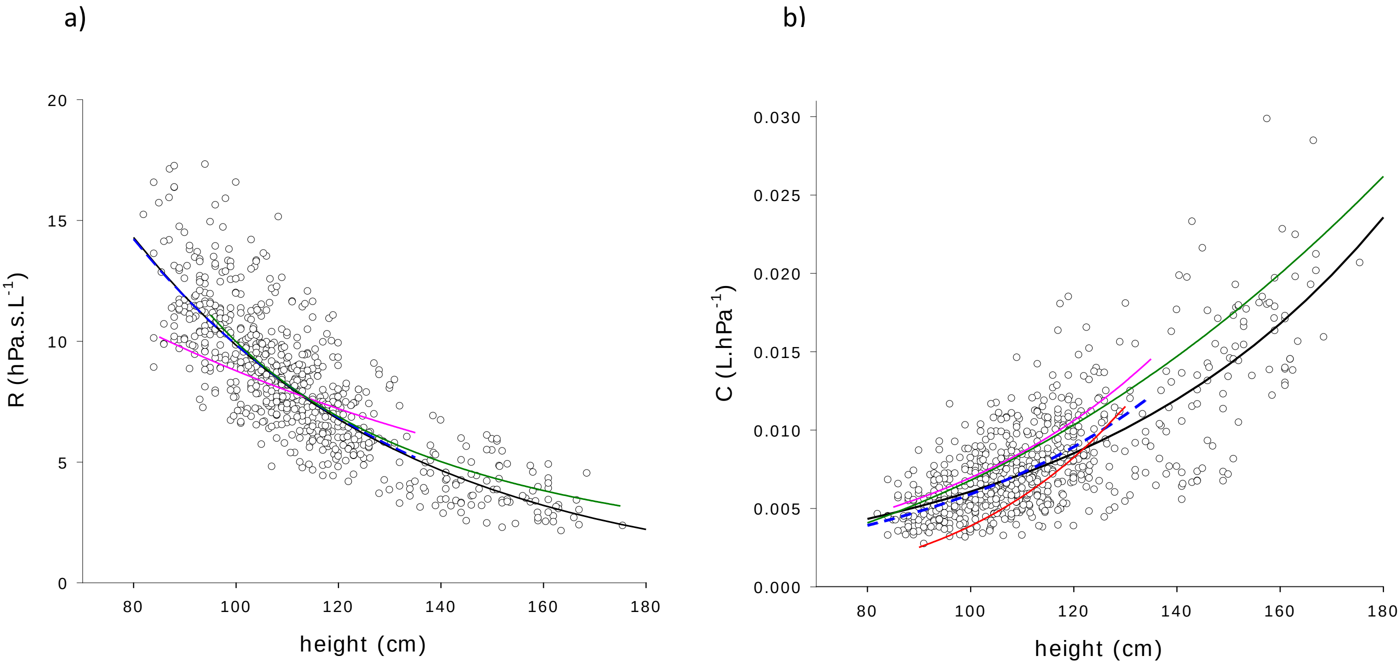

Figure 1: (a) Respiratory system resistance (R) and (b) compliance (C) vs height in healthy children and adolescents. Black solid and blue dashed lines indicate the regressions on the total population (n=692) and the 3-7- yr age range (n=573), respectively. R and C vs height regressions from previous work are also plotted for comparison: Hantos et al. [22] (green), Mazurek et al. [25] (red) and Shackleton et al. [41] (pink).

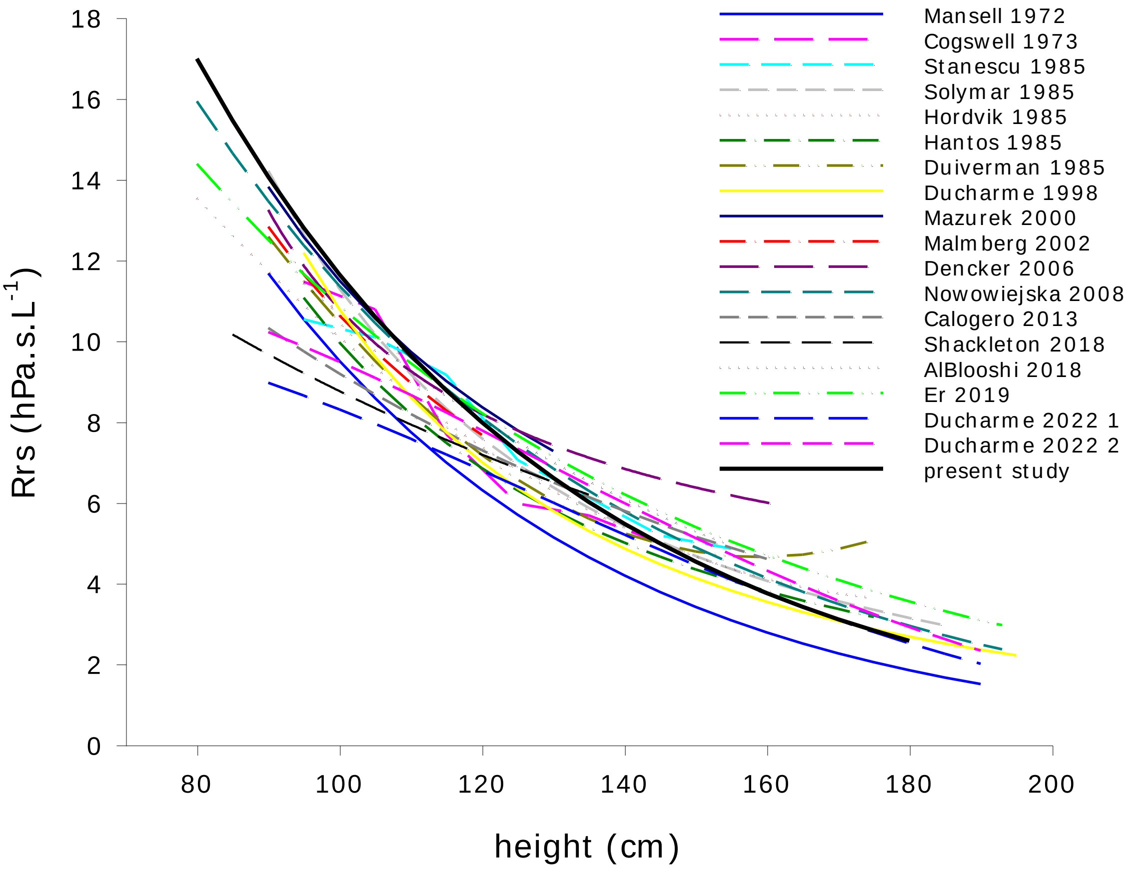

Figure 2: Comparison of respiratory resistance (Rrs) *vs* height relationships established in the present and previous studies (see Table 3 for details).

References

1. Stern DA, Morgan WJ, Wright AL, et al. Poor airway function in early infancy and lung function by age 22 years: a non-selective longitudinal cohort study. The Lancet. 2007;370(9589):758-64.
2. Duong M, Islam S, Rangarajan S, et al. Mortality and cardiovascular and respiratory morbidity in individuals with impaired FEV1 (PURE): an international, community-based cohort study. The Lancet Global Health. 2019;7(5):e613-e23.
3. Santus P, Radovanovic D, Pecchiari M, et al. The relevance of targeting treatment to small airways in asthma and COPD. Respiratory Care. 2020;65(9):1392-412.
4. Skylogianni E, Douros K, Anthracopoulos MB, et al. The Forced Oscillation Technique in Paediatric Respiratory Practice. Paediatr Respir Rev. 2016;18:46-51.
5. Bates JH, Irvin CG, Farré R, et al. Oscillation mechanics of the respiratory system. Comprehensive Physiology. 2011;1(3):1233-72.
6. Hantos Z. Intra-breath oscillometry for assessing respiratory outcomes. Current Opinion in Physiology. 2021;22:100441.
7. Czövek D, Shackleton C, Hantos Z, et al. Tidal changes in respiratory resistance are sensitive indicators of airway obstruction in children. Thorax. 2016;71(10):907-15.
8. Lorx A, Czövek D, Gingl Z, et al. Airway dynamics in COPD patients by within-breath impedance tracking: effects of continuous positive airway pressure. European Respiratory Journal. 2017;49(2).
9. Gray DM, Czovek D, McMillan L, et al. Intra-breath measures of respiratory mechanics in healthy African infants detect risk of respiratory illness in early life. The European respiratory journal. 2019;53(2).
10. Chiabai J, Friedrich FO, Fernandes MTC, et al. Intrabreath oscillometry is a sensitive test for assessing disease control in adults with severe asthma. Annals of Allergy, Asthma and Immunology. 2021;127(3):372-7.
11. Stanojevic S, Wade A, Lum S, et al. Reference equations for pulmonary function tests in preschool children: a review. Pediatric pulmonology. 2007;42(10):962-72.
12. Lum S, Bountziouka V, Sonnappa S, et al. Lung function in children in relation to ethnicity, physique and socioeconomic factors. The European respiratory journal. 2015;46(6):1662-71.
13. Sonnappa S, Lum S, Kirkby J, et al. Disparities in pulmonary function in healthy children across the Indian urban-rural continuum. American journal of respiratory and critical care medicine. 2015;191(1):79-86.
14. Calogero C, Simpson SJ, Lombardi E, et al. Respiratory impedance and bronchodilator responsiveness in healthy children aged 2-13 years. Pediatr Pulmonol. 2013;48(7):707-15.
15. Hordvik NL, König P, Morris DA, et al. Normal values for forced oscillatory respiratory resistance in children. Pediatric Pulmonology. 1985;1(3):145-8.
16. Nowowiejska B, Tomalak W, Radliński J, et al. Transient reference values for impulse oscillometry for children aged 3-18 years. Pediatr Pulmonol. 2008;43(12):1193-7.
17. Malmberg La, Pelkonen A, Poussa T, et al. Determinants of respiratory system input impedance and bronchodilator response in healthy Finnish preschool children. Clinical physiology and functional imaging. 2002;22(1):64-71.
18. Stănescu D, Moavero NE, Veriter C, et al. Frequency dependence of respiratory resistance in healthy children. J Appl Physiol Respir Environ Exerc Physiol. 1979;47(2):268-72.
19. Mansell A, Levison H, Kruger K, et al. Measurement of Respiratory Resistance in Children by Forced Oscillations. American Review of Respiratory Disease. 1972;106(5):710-4.

20. Cogswell J. Forced oscillation technique for determination of resistance to breathing in children. Archives of Disease in Childhood. 1973;48(4):259-66.
21. Solymar L, Aronsson PH, Sixt R. The forced oscillation technique in children with respiratory disease. Pediatr Pulmonol. 1985;1(5):256-61.
22. Hantos Z, Daróczy B, Gyurkovits K. Total respiratory impedance in healthy children. Pediatr Pulmonol. 1985;1(2):91-8.
23. Ducharme FM, Davis GM, Ducharme GR. Pediatric reference values for respiratory resistance measured by forced oscillation. Chest. 1998;113(5):1322-8.
24. Dencker M, Malmberg LP, Valind S, et al. Reference values for respiratory system impedance by using impulse oscillometry in children aged 2-11 years. Clinical Physiology and Functional Imaging. 2006;26(4):247-50.
25. Mazurek H, Willim G, Marchal F, et al. Input respiratory impedance measured by head generator in preschool children. Pediatr Pulmonol. 2000;30(1):47-55.
26. Duiverman E, Clement J, Van de Woestijne K, et al. Forced oscillation technique. Reference values for resistance and reactance over a frequency spectrum of 2-26 Hz in healthy children aged 2.3-12.5 years. Bulletin Europeen de Physiopathologie Respiratoire. 1985;21(2):171-8.
27. Ducharme FM, Smyrnova A, Lawson CC, et al. Reference values for respiratory sinusoidal oscillometry in children aged 3 to 17 years. Pediatr Pulmonol. 2022; 57:2092-2102
28. Shackleton C, Barraza-Villarreal A, Chen L, et al. Reference ranges for Mexican preschool-aged children using the forced oscillation technique. Archivos de Bronconeumología (English Edition). 2013;49(8):326-9.
29. Udomittipong K, Srisukhon W, Nimmannit A, et al. Respiratory impedance reference values for forced oscillation technique predicted by arm span and height in Thai preschool children. Pediatric allergy, immunology, and pulmonology. 2017;30(2):97-102.
30. AlBlooshi A, AlKalbani A, Narchi H, et al. Respiratory function in healthy Emirati children using forced oscillations. Pediatric pulmonology. 2018;53(7):936-41.
31. Gochicoa-Rangel L, Torre-Bouscoulet L, Martínez-Briseño D, et al. Values of impulse oscillometry in healthy Mexican children and adolescents. Respiratory Care. 2015;60(1):119-27.
32. Lee JY, Seo JH, Kim HY, et al. Reference values of impulse oscillometry and its utility in the diagnosis of asthma in young Korean children. Journal of Asthma. 2012;49(8):811-6.
33. Lai S-H, Yao T-C, Liao S-L, et al. Reference Value of Impulse Oscillometry in Taiwanese Preschool Children. Pediatrics and neonatology. 2015;56(3):165-70.
34. Er I, Gunlemez A, Baydemir C, et al. Impulse oscillometry reference values and correlation with predictors in Turkish preschool children. Turkish Journal of Pediatrics. 2019;61(4):560-7.
35. Africa S. Mid-Year Population Estimates—P0302. Statistics South Africa. 2019.URL: https://www.statssa.gov.za
36. Radics BL, Gyurkovits Z, Makan G, et al. Respiratory Oscillometry in Newborn Infants: Conventional and Intra-Breath Approaches. Frontiers in Pediatrics. 2022;10.
37. King GG, Bates J, Berger KI, et al. Technical standards for respiratory oscillometry. European Respiratory Journal. 2020;55(2).
38. Gray D, Willemse L, Visagie A, et al. Determinants of early-life lung function in African infants. Thorax. 2017;72(5):445-50.
39. Githinji LN, Gray DM, Hlengwa S, et al. Lung Function in South African Adolescents Infected Perinatally with HIV and Treated Long-Term with Antiretroviral Therapy. Annals of the American Thoracic Society. 2017;14(5):722-9.
40. World Health Organisation (WHO). Integrated management of childhood illness: distance learning course; 2014. 2021.
41. Shackleton C, Czovek D, Grimwood K, et al. Defining 'healthy'in preschool-aged children for forced oscillation technique reference equations. Respirology. 2018;23(4):406-13.
42. Sly PD, Hantos Z. The international collaboration to improve respiratory health in children (INCIRCLE) ERS clinical research collaboration. Eur Respiratory Soc; 2018.1801867

43. Miller TK, Pimmel RL. Forced noise mechanical parameters during inspiration and expiration. J Appl Physiol Respir Environ Exerc Physiol. 1982;52(6):1530-4.
44. Quanjer PH, Stanojevic S, Cole TJ, et al. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. The European respiratory journal. 2012;40(6):1324-43.
45. Dandurand RJ, Lavoie J-P, Lands LC, et al. Comparison of oscillometry devices using active mechanical test loads. ERJ Open Research. 2019;5(4):00160-2019.
46. Lundblad LK, Siddiqui S, Bossé Y, et al. Applications of oscillometry in clinical research and practice. Canadian Journal of Respiratory, Critical Care, and Sleep Medicine. 2021;5(1):54-68.
47. Gray DM, Czovek D, McMillan L, et al. Intra-breath measures of respiratory mechanics in healthy African infants detect risk of respiratory illness in early life. The European respiratory journal. 2019;53(2).
48. Smith S-J, Gray DM, MacGinty RP, et al. Choosing the Better Global Lung Initiative 2012 Equation in South African Population Groups. American journal of respiratory and critical care medicine. 2020;202(12):1724-7.
49. Harrison P. Urbanization: the policies and politics of informal settlement in South Africa: a historical perspective. Africa Insight. 1992;22(1):14-22.

SUPPLEMENTARY MATERIAL

Normal values of respiratory oscillometry in South African children and adolescents

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Table S1: Demographic data stratified by age

Years	3 (n=104)	4 (n=131)	5 (n=114)	6 (n=128)	7 (n=103)	8 (n=9)	9 (n=7)	10 (n=12)	11 (n=23)	12 (n=11)	13 (n=11)	14 (n=10)	15 (n=9)	16 (n=9)	17 (n=11)	Total (n=692)
Site																
CTAAC	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (90.0%)	9 (100%)	9 (100%)	11 (100%)	38 (5.5%)
HCSOC	0 (0.0%)	0 (0.0%)	1 (0.9%)	0 (0.0%)	6 (5.8%)	9 (100%)	7 (100%)	12 (100%)	23 (100%)	11 (100%)	11 (100%)	1 (10.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	81 (11.7%)
DCHS	104 (100%)	131 (100%)	113 (99.1%)	128 (100%)	97 (94.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	573 (82.8%)
Sex																
Female	52 (50.0%)	69 (52.7%)	53 (46.5%)	63 (49.2%)	48 (46.6%)	6 (66.7%)	3 (42.9%)	4 (33.3%)	9 (39.1%)	3 (27.3%)	5 (45.4%)	3 (30.0%)	5 (55.6%)	5 (55.6%)	47 (63.6%)	335 (48.4%)
Male	52 (50%)	62 (47.33%)	61 (53.51%)	65 (50.78%)	55 (53.40%)	3 (33.33%)	4 (57.14%)	8 (66.67%)	14 (60.87%)	8 (72.73%)	6 (54.55%)	7 (70%)	4 (44.44%)	4 (44.44%)	4 (36.36%)	357 (51.59%)
Weight (kg)*	13.50 (12.6; 14.3)	15.3 (14.4; 17.1)	17.8 (16.1; 19.5)	19. 5 (17.4; 21.9)	21.1 (19.2; 23.9)	29.5 (25.5; 30.0)	28.5 (26.4; 37.0)	36.2 (31.0; 40.8)	35.7 (30.7; 42.9)	41.0 (31.1; 49.8)	45.2 (34.2; 49.8)	49.0 (44.0; 62.0)	52.0 (41.0; 69.0)	55.0 (49.0; 61.0)	55.0 (49.0; 61.0)	18.2 (15.3; 23.1)
WAZ*	-0.54 (-1.11; -0.02)	-0.58 (-1.05; 0.25)	-0.37 (-1.09; 0.31)	-0.50 (-1.38; 0.34)	-0.63 (-1.37; 0.34)	0.66 (-0.07; 1.19)	-0.17 (-0.61; 1.33)	0.88 (-0.10; 1.56)	0.28 (-0.74; 0.80)	0.21 (-1.34; 1.10)	0.31 (-1.40; 0.63)	-0.11 (-0.51; 0.91)	-0.77 (-1.58; 1.42)	0.08 (-1.28; 0.62)	-0.04 (-1.42; 0.95)	-0.42 (-1.11; 0.35)
Height (cm)*	92.3 (89.0; 95.0)	101.0 (97.0; 104.5)	107.0 (104.0; 111.4)	114.0 (110.0; 117.5)	120.0 (115.5; 124.0)	127.0 (126.0; 131.0)	132.0 (120.0; 145.0)	140.3 (138.3; 145.0)	141.0 (136.7; 146.0)	151.0 (143.0; 152.0)	144.0 (142.0; 158.5)	156.8 (153.0; 161.0)	158.0 (151.0; 159.0)	160.5 (156.6; 163.0)	161.0 (157.5; 167.0)	110.0 (101.0; 120.0)
HAZ*	-1.18 (-2.00; -0.49)	-0.69 (-1.51; 0.04)	-0.69 (-1.40; 0.16)	-0.64 (-1.26; 0.13)	-0.41 (-1.25; 0.29)	0.01 (-0.38; 0.47)	-0.42 (-1.79; 1.62)	0.27 (-0.22; 0.82)	-0.46 (-1.29; 0.09)	0.03 (-1.13; 0.53)	-1.33 (-1.99; 0.58)	-0.79 (-1.37; -0.20)	-1.46 (-1.49; -0.49)	-0.82 (-1.82; -0.22)	-0.31 (-1.61; -0.14)	-0.65 (-1.43; 0.05)
BMI (kg/m^2)*	15.7 (15.0; 16.9)	15.3 (14.5; 16.3)	15.2 (14.4; 16.0)	15.0 (13.9; 16.2)	14.7 (14.1; 15.8)	16.9 (15.6; 18.5)	16.4 (15.4; 19.4)	17.9 (16.6; 20.3)	18.9 (15.6; 20.1)	19.4 (15.9; 21.8)	18.7 (17.0; 24.0)	19.4 (18.0; 24.7)	19.6 (18.4; 27.8)	21.8 (17.9; 23.7)	21.8 (17.9; 23.7)	15.5 (14.5; 17.0)
BMI-Z*	0.22 (-0.38; 1.09)	0.00 (-0.62; 0.73)	-0.04 (-0.61; 0.56)	-0.27 (-1.01; 0.53)	-0.45 (-1.15; 0.19)	0.55 (-0.14; 1.21)	0.10 (-0.44; 1.33)	0.71 (0.10; 1.47)	0.82 (-0.88; 1.27)	0.39 (-0.85; 1.59)	0.15 (-0.87; 1.58)	0.23 (-0.62; 1.67)	-0.09 (-0.63; 1.88)	0.37 (-1.15; 0.86)	0.47 (-0.46; 1.10)	-0.04 (-0.70; 0.76)

CTAAC: Cape Town Adolescent Antiretroviral Cohort; HCSOC: Healthy children at surgical outpatient clinics; DCHS: Drakenstein Child Health Study; BMI: Body mass index; WAZ: weight for age z-score; HAZ: height for age z-score; BMI-Z: Body mass index z-score.

*Median (interquartile range)

Table S2: Summary of respiratory impedance variables stratified by age

	Standard											Intrabreath					
years	**R_6**	**R_8**	**R_{10}**	**X_6**	**X_8**	**X_{10}**	**R_6-R_{20}**	**F_{res}**	**Ax**	**R**	**C**	**R_{eE}**	**R_{eI}**	**X_{eE}**	**X_{eI}**	**ΔR**	**ΔX**
3	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=51**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**	**n=104**
	13.23 (11.81; 15.35)	12.50 (11.31; 14.29)	12.05 (10.83; 13.65)	-4.56 (-5.63; -3.57)	-3.79 (-4.69; -3.08)	-3.07 (-3.76; -2.41)	2.76 (1.95; 3.63)	25.21 (22.71; 27.84)	45.22 (34.66; 61.22)	11.39 (10.09; 12.95)	5.05 (4.21; 5.78)	11.69 (10.47; 13.63)	10.29 (9.26; 12.43)	-2.30 (-3.13; -1.48)	-3.10 (-3.75; -2.35)	1.22 (0.66; 2.43)	0.80 (-0.01; 1.37)
4	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=89**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**	**n=131**
	11.71 (9.96; 13.23)	10.72 (9.48; 12.34)	10.27 (9.16; 12.00)	-3.45 (-4.67; -2.67)	-2.91 (-3.88; -2.02)	-2.28 (-3.29; -1.60)	2.47 (1.57; 3.48)	22.01 (18.25; 24.69)	28.90 (19.64; 48.27)	9.70 (8.73; 10.93)	6.03 (4.66; 7.61)	10.02 (8.77; 11.73)	9.23 (8.11; 10.62)	-1.51 (-2.57; -0.78)	-2.33 (-3.12; -1.68)	0.76 (-0.18; 1.62)	0.69 (0.01; 1.41)
5	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=83**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**	**n=114**
	10.14 (8.60; 12.20)	9.58 (8.26; 10.98)	9.20 (7.93; 10.63)	-2.91 (-3.76; -2.38)	-2.48 (-3.37; -1.95)	-2.04 (-2.73; -1.44)	2.17 (1.51; 3.11)	21.02 (18.15; 25.08)	28.26 (16.37; 40.02)	8.40 (7.36; 9.85)	6.79 (5.67; 8.39)	8.66 (7.37; 10.26)	7.94 (6.86; 9.62)	-1.28 (-2.32; -0.73)	-1.95 (-2.60; -1.45)	0.42 (-0.22; 1.20)	0.52 (0.07; 0.97)
6	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=109**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**	**n=128**
	9.05 (8.13; 10.47)	8.58 (7.57; 9.94)	8.30 (7.31; 9.59)	-2.74 (-3.52; -2.15)	-2.18 (-2.74; -1.50)	-1.68 (-2.16; -1.17)	1.86 (1.27; 2.72)	20.71 (17.93; 23.73)	20.08 (14.48; 29.75)	7.68 (6.76; 8.80)	7.44 (6.38; 9.34)	7.71 (6.69; 9.08)	7.54 (6.35; 8.90)	-1.17 (-1.60; -0.56)	-1.70 (-2.18; -1.15)	0.41 (-0.34; 1.03)	0.57 (0.10; 0.87)
7	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=88**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**	**n=103**
	7.62 (6.52; 9.38)	7.33 (6.15; 8.56)	6.90 (6.14; 8.47)	-2.03 (-2.98; -1.69)	-1.61 (-2.31; -1.31)	-1.39 (-1.92; -0.90)	1.71 (1.10; 2.46)	19.28 (16.29; 22.93)	16.48 (9.94; 27.34)	6.43 (5.63; 7.67)	9.66 (7.60; 11.16)	6.57 (5.57; 7.97)	6.30 (5.44; 7.38)	-0.80 (-1.78; -0.36)	-1.39 (-1.91; -0.96)	0.29 (-0.19; 0.63)	0.54 (0.07; 0.89)
8	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=4**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**
	7.14 (6.46; 9.05)	6.30 (5.93; 8.56)	5.78 (5.65; 7.60)	-2.02 (-3.32; -1.95)	-2.44 (-3.50; -2.00)	-2.34 (-3.42; -1.60)	2.29 (1.01; 4.00)	21.07 (17.74; 25.69)	35.40 (17.57; 60.76)	5.76 (5.36; 6.18)	7.41 (5.53; 10.94)	6.10 (5.27; 7.22)	6.44 (4.43; 6.73)	-2.17 (-3.23; -1.20)	-1.57 (-2.51; -1.20)	0.55 (0.06; 1.67)	0.004 (-0.66; 0.45)
9	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=5**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**	**n=7**
	7.02 (5.48; 10.79)	6.46 (4.87; 9.72)	5.89 (4.43; 9.21)	-2.36 (-4.19; -1.36)	-2.54 (-2.96; -1.44)	-1.93 (-3.42; -0.72)	2.40 (1.13; 3.34)	20.17 (17.48; 25.79)	32.12 (8.70; 54.33)	5.04 (3.98; 8.38)	6.99 (5.29; 13.70)	6.11 (3.89; 8.07)	5.12 (4.12; 8.14)	-1.35 (-2.64; -0.50)	-1.71 (-2.91; -0.42)	0.22 (-0.07; 1.00)	-0.08 (-0.28; 0.27)
10	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=8**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**	**n=12**
	5.86 (4.67; 6.63)	5.74 (4.36; 6.58)	5.56 (4.51; 6.16)	-2.32 (-3.26; -1.32)	-1.55 (-2.59; -1.18)	-1.23 (-2.24; -0.85)	1.04 (0.65; 2.21)	19.97 (18.11; 23.99)	20.41 (10.63; 39.11)	5.31 (3.84; 5.80)	9.51 (7.14; 14.92)	5.12 (3.99; 6.90)	4.67 (3.72; 5.33)	-1.16 (-2.31; -0.35)	-1.17 (-1.84; -0.76)	0.75 (0.06; 1.38)	-0.13 (-0.37; 0.26)
11	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=21**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**	**n=23**
	5.15 (4.34; 5.85)	4.62 (3.83; 5.64)	4.42 (3.79; 5.22)	-1.92 (-2.43; -1.46)	-1.61 (-2.04; -1.19)	-1.29 (-1.89; -0.87)	1.64 (0.88; 2.43)	18.57 (16.46; 20.98)	15.77 (10.44; 24.20)	3.89 (3.41; 4.51)	9.84 (7.22; 13.01)	3.98 (3.72; 4.58)	3.55 (3.16; 4.18)	-0.93 (-1.41; -0.51)	-0.89 (-1.58; -0.52)	0.40 (0.20; 0.77)	-0.09 (-0.34; 0.10)
12	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=10**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**
	4.50 (3.73;	4.35 (3.75;	4.18 (3.33;	-1.96 (-2.16;	-1.15 (-2.12; -	-0.91 (-1.70;	1.09 (0.36;	19.71 (16.04;	18.22 (6.17;	4.16 (2.44;	13.42 (8.91;	4.24 (3.14;	3.42 (2.51;	-0.55 (-0.91; -	-0.48 (-1.29; -	0.54 (0.36;	-0.10 (-0.20;

	6.61)	6.70)	5.66)	-1.05)	0.81)	-0.17)	2.30)	24.87)	19.35)	5.42)	17.85)	5.22)	3.83)	0.40)	0.36)	1.79)	0.02)
13	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=9**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**
	4.19 (3.51; 5.57)	3.91 (3.25; 4.53)	3.99 (3.24; 4.20)	-1.56 (-1.89; -1.32)	-1.22 (-1.95; -0.97)	-0.86 (-1.40; -0.60)	0.86 (0.38; 1.61)	17.59 (14.45; 19.18)	11.80 (5.98; 20.48)	3.33 (3.11; 3.85)	12.52 (10.51; 15.45)	3.58 (2.89; 3.96)	2.56 (2.33; 3.79)	-0.69 (-1.05; 0.03)	-0.74 (-1.29; -0.36)	0.58 (0.34; 1.08)	0.07 (-0.31; 0.43)
14	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**	**n=10**
	4.50 (3.51; 5.30)	4.30 (3.23; 5.04)	4.29 (3.30; 4.84)	-1.22 (-1.62; -0.90)	-0.94 (-1.01; -0.35)	-0.63 (-0.83; -0.56)	0.41 (0.01; 0.77)	15.74 (13.00; 20.58)	6.11 (1.40; 9.42)	4.08 (3.42; 4.82)	16.98 (15.29; 18.07)	3.43 (2.98; 4.00	3.27 (2.49; 3.66)	-0.28 (-0.73; 0.31)	-0.50 (-0.67; -0.20)	0.27 (0.11; 0.57)	0.23 (0.15; 0.43)
15	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=8**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**
	3.77 (3.16; 4.74)	4.00 (3.31; 4.66)	3.86 (3.35; 4.54)	-1.19 (-1.47; -0.92)	-0.94 (-1.13; -0.50)	-0.67 (-0.81; -0.43)	0.05 (-0.04; 0.53)	14.00 (11.95; 15.27)	4.77 (3.07; 6.80)	3.82 (3.43; 4.55)	17.27 (14.48; 18.07)	3.63 (3.06; 4.19)	2.78 (2.55; 3.53)	-0.17 (-0.46; 0.16)	-0.45 (-0.54; -0.14)	0.57 (0.34; 0.76)	0.08 (-0.001; 0.27)
16	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=8**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**	**n=9**
	3.39 (3.01; 4.11)	3.02 (2.93; 3.78)	3.18 (2.74; 3.79)	-1.23 (-1.40; -1.19)	-0.66 (-0.70; -0.59)	-0.37 (-0.66; -0.28)	0.23 (0.01; 0.58)	14.83 (13.26; 15.94)	4.18 (4.36; 4.33)	3.19 (2.67; 3.83)	19.24 (17.78; 19.75)	2.97 (2.46; 3.84)	2.50 (2.20; 3.32)	-0.02 (-0.25; -0.02)	-0.42 (-0.75; -0.13)	0.29 (0.15; 0.67)	0.30 (0.03; 0.46)
17	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**	**n=11**
	3.41 (2.88; 4.59)	3.29 (2.32; 4.34)	3.13 (2.39; 4.08)	-1.23 (-1.50; -1.11)	-0.79 (-1.07; -0.38)	-0.39 (-0.77; -0.15)	0.47 (0.06; 0.58)	14.56 (12.23; 16.45)	4.16 (2.23; 7.62)	3.31 (2.37; 4.18)	15.89 (13.85; 17.98)	2.70 (2.00; 3.33)	2.22 (2.01; 2.93)	-0.28 (-0.39; 0.12)	-0.44 (-0.64; -0.07)	0.23 (-0.04; 0.42)	0.17 (0.05; 0.32)
Total	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=514**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**	**n=692**
	9.62 (7.19; 12.26)	9.15 (6.90; 11.33)	8.88 (6.65; 10.79)	-2.83 (-3.95; -1.97)	-2.34 (-3.31; -1.51)	-1.84 (-2.77; -1.18)	2.01 (1.15; 2.99)	20.67 (17.16; 24.57)	24.30 (14.26; 39.53)	8.11 (6.08; 10.11)	7.20 (5.48; 9.85)	8.22 (6.22; 10.60)	7.85 (5.97; 9.62)	-1.23 (-2.23; -0.55)	-1.87 (-2.68; -1.13)	0.53 (-0.04; 1.22)	0.50 (-0.05; 0.97)

R_6, R_8 and R_{10}: resistance at 6, 8 and 10 Hz; X_6, X_8 and X_{10}: reactance at 6, 8 and 10 Hz; F_{res}: resonance frequency; R_6-R_{20}: difference between resistance at 6 Hz and resistance at 20 Hz; Ax: area under the reactance curve; R: resistance from model fitting; C: compliance from model fitting; R_{eI}: resistance at end inspiration; R_{eE}: resistance at end expiration; ΔR: R_{eE}-R_{eI} ; X_{eI}: reactance at end inspiration, R_{eE}: reactance at end expiration; ΔX: X_{eE}-X_{eI}.

Median (IQR) values.

Units: R and X variables: hPa.L.s^{-1}; C: L.hPa^{-1}; F_{res}: Hz; Ax: hPa.L^{-1}.

Table S3 : Comparison between models adjusted for height only and height, sex and ethnicity

	Model with height only (n=692)			Model with height, sex, and ethnicity (n=692)				
	Height Coefficient (95% CI)	BIC value	Adj. R^2	Height Coefficient (95% CI)	Sex Coefficient (95% CI)	Ethnicity Coefficient (95% CI)	BIC value	Adj. R^2
R_6	**-0.019 (-0.020; -0.018)**	-156.50	0.723	**-0.019 (-0.020; -0.018)**	**-0.032 (-0.064; -0.000)**	0.008 (-0.024; 0.041)	-147.55	0.724
R_8	**-0.019 (-0.020; -0.018)**	-187.05	0.735	**-0.019 (-0.020; -0.018)**	-0.028 (-0.059; 0.003)	0.006 (-0.026; 0.038)	-177.12	0.735
R_{10}	**-0.019 (-0.020; -0.018)**	-227.68	0.747	**-0.019 (-0.020; -0.018)**	-0.023 (-0.054; 0.007)	0.019 (-0.012; 0.049)	-218.14	0.745
X_6	**-727 (-793; -661)**	2189.17	0.405	**-731 (-797; -665)**	0.089 (-0.085; 0.264)	0.166 (-0.009; 0.341)	2197.61	0.407
X_8	**-646 (-702; -590)**	1967.53	0.425	**-649 (-795; -593)**	**0.182 (0.034; 0.330)**	**0.163 (0.014; 0.311)**	1969.75	0.433
X_{10}	**-530 (-583; -478)**	1886.30	0.359	**-533 (-586; -480)**	0.118 (-0.022; 0.258)	**0.141 (0.001; 0.281)**	1892.48	0.364
F_{res}	**-0.006 (-0.007; -0.005)**	-131.29	0.230	**-0.006 (-0.007; -0.005)**	-0.010 (-0.047; 0.026)	-0.004 (-0.042; 0.033)	-119.20	0.227
R_6-R_{20}	**-0.031 (-0.036; -0.026)**	2258.30	0.177	**-0.031 (-0.037; -0.026)**	-0.092 (-0.275; 0.092)	-0.152 (-0.336; 0.033)	2267.66	0.179
Ax	**-0.029 (-0.031; -0.026)**	1322.14	0.416	**-0.029 (-0.031; -0.026)**	-0.052 (-0.146; 0.041)	-0.014 (-0.108; 0.080)	1333.89	0.416
R	**-0.019 (-0.020; -0.018)**	-220.75	0.739	**-0.019 (-0.019; -0.018)**	-0.025 (-0.055; 0.006)	0.023 (-0.008; 0.054)	-212.14	0.740
C	**0.017 (0.016; 0.018)**	284.34	0.523	**0.017 (0.016; 0.018)**	0.038 (-0.006; 0.082)	0.045 (0.000; 0.089)	290.30	0.526
X_{eE}	**-409 (-476; -343)**	2201.57	0.174	**-408 (-474; -341)**	**0.197 (0.021; 0.373)**	0.055 (-0.121; 0.232)	2209.31	0.178
X_{eI}	**-577 (-630; -524)**	1894.15	0.397	**-579 (-632; -526)**	**0.184 (0.044; 0.325)**	0.137 (-0.004; 0.277)	1896.54	0.404
ΔR	**-0.014 (-0.020; -0.009)**	2307.58	0.040	**-0.014 (-0.020; -0.009)**	0.058 (-0.132; 0.249)	-0.101 (-0.292; 0.091)	2319.28	0.039
ΔX	**-0.012 (-0.016; -0.008)**	1870.89	0.050	**-0.012 (-0.016; -0.008)**	0.012 (-0.127; 0.151)	-0.090 (-0.230; 0.050)	1882.34	0.049

R_6, R_8 and R_{10}: resistance at 6, 8 and 10 Hz; X_6, X_8 and X_{10}: reactance at 6, 8 and 10 Hz; F_{res}: resonance frequency; R_6-R_{20}: difference between resistance at 6 Hz and resistance at 20 Hz; Ax: area under the reactance curve; R: resistance from model fitting; C: compliance from model fitting; R_{eI}: resistance at end inspiration; R_{eE}: resistance at end expiration; ΔR: R_{eE}-R_{eI} ; X_{eI}: reactance at end inspiration, R_{eE}: reactance at end expiration; ΔX: X_{eE}-X_{eI}. BIC: Bayesian Information Criterion; Adj R^2: adjusted R^2. Statistically significant results are printed in bold.

Units: R and X variables: $hPa.L.s^{-1}$; C: $L.hPa^{-1}$; F_{res}: Hz; Ax: $hPa.L^{-1}$.

Table S4: Reference equations for children 3 to 7 years of age from the DCHS cohort

Outcome	Equation	Adj R^2	SEE
$\mathbf{R_6}$ (hPa.s.L^{-1})	exp(4.23 - 0.0178·Ht)	0.466	0.203
$\mathbf{R_8}$ (hPa.s.L^{-1})	exp(4.17 - 0.0178·Ht)	0.479	0.198
$\mathbf{R_{10}}$ (hPa.s.L^{-1})	exp(4.14 - 0.0179·Ht)	0.490	0.194
$\mathbf{X_6}$ (hPa.s.L^{-1})	5.06-888·Ht^{-1}	0.333	1.211
$\mathbf{X_8}$ (hPa.s.L^{-1})	4.81 -798·Ht^{-1}	0.366	1.011
$\mathbf{X_{10}}$ (hPa.s.L^{-1})	3.72 -630/Ht	0.291	0 .946
$\mathbf{F_{res}}$ (Hz)	exp(3.85 - 0.0074·Ht)	0.116	0.204
$\mathbf{R_6}$-$\mathbf{R_{20}}$ (hPa.s.L^{-1})	5.69 - 0.0316·Ht	0.066	1.248
AX (hPa.L^{-1})	exp(7 - 0.0353·Ht)	0.309	0.561
R (hPa.s.L^{-1})	exp(4.12 - 0.0184·Ht)	0.510	0.192
C (L.hPa^{-1})	exp(-0.30 + 0.0207·Ht)	0.385	0.279
$\mathbf{R_{eE}}$ (hPa.s.L^{-1})	exp(4.30 - 0.0198·Ht)	0.486	0.216
$\mathbf{R_{eI}}$ (hPa.s.L^{-1})	exp(3.93 - 0.0170·Ht)	0.408	0.218
$\mathbf{X_{eE}}$ (hPa.s.L^{-1})	3.11 - 502·Ht^{-1}	0.139	1.199
$\mathbf{X_{eI}}$ (hPa.s.L^{-1})	3.96 - 651·Ht^{-1}	0.301	0.955
ΔR (hPa.s.L^{-1})	4.96 - 0.0403·Ht	0.095	1.316
ΔX (hPa.s.L^{-1})	1.97 - 0.0132·Ht	0.018	0.989

R_6, R_8 and R_{10}: resistance at 6, 8 and 10 Hz; X_6, X_8 and X_{10}: reactance at 6, 8 and 10 Hz; F_{res}: resonance frequency; R_6-R_{20}: difference between resistance at 6 Hz and resistance at 20 Hz; Ax: area under the reactance curve; R: resistance from model fitting; C: compliance from model fitting; R_{eI}: resistance at end inspiration; R_{eE}: resistance at end expiration; ΔR: R_{eE}-R_{eI} ; X_{eI}: reactance at end inspiration, R_{eE}: reactance at end expiration; ΔX: X_{eE}-X_{eI};. Adj R^2: adjusted R^2; SEE: standard error of the estimate.

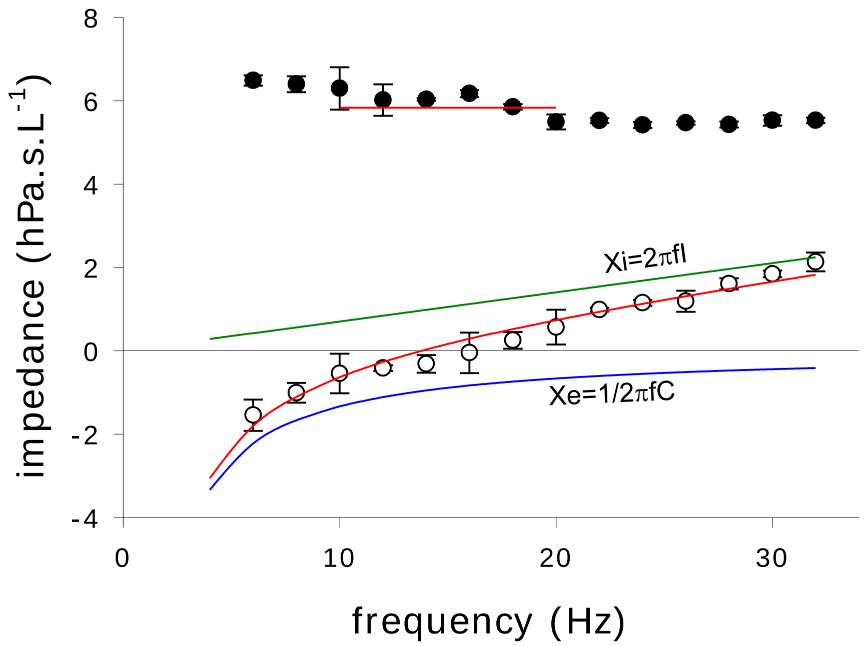

Figure S1: Illustration of the resistance (R) - inertance (I) – compliance (C) model fitting to measured impedance data. Mean values of resistance (●) and reactance (○) from repeated measurements, whiskers indicate standard deviation. Model fitting curves are plotted in red. R was obtained as the mean value in the 10-20-Hz frequency (f) range; I and C were obtained from fitting the reactance (X) data by the model $X= 2\pi fI-1/(2\pi fC)$. Green and blue lines, respectively, illustrate the inertial (Xi) and elastic (Xe) components of the total X.

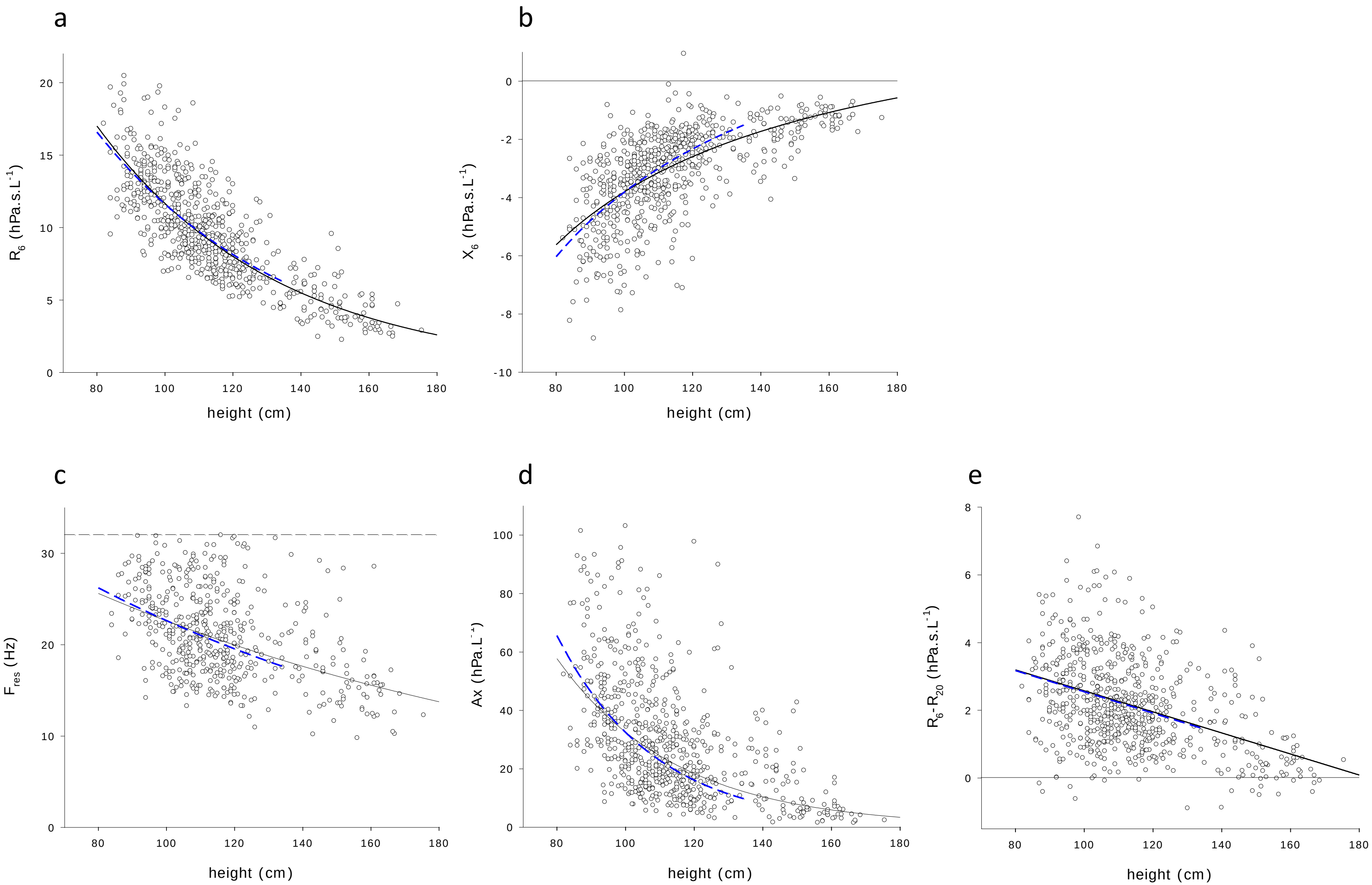

Figure S2: Conventional oscillometry measures *vs* height: a) resistance at 6 Hz (R_6) , b) reactance at 6 Hz (X), c) resonance frequency (F_{res}), d) area under the reactance curve (Ax) and e) frequency dependence of resistance (R_6-R_{20}). Solid and dashed lines, respectively, indicate prediction equations for the 3-17-yr and 3-7-yr ranges.

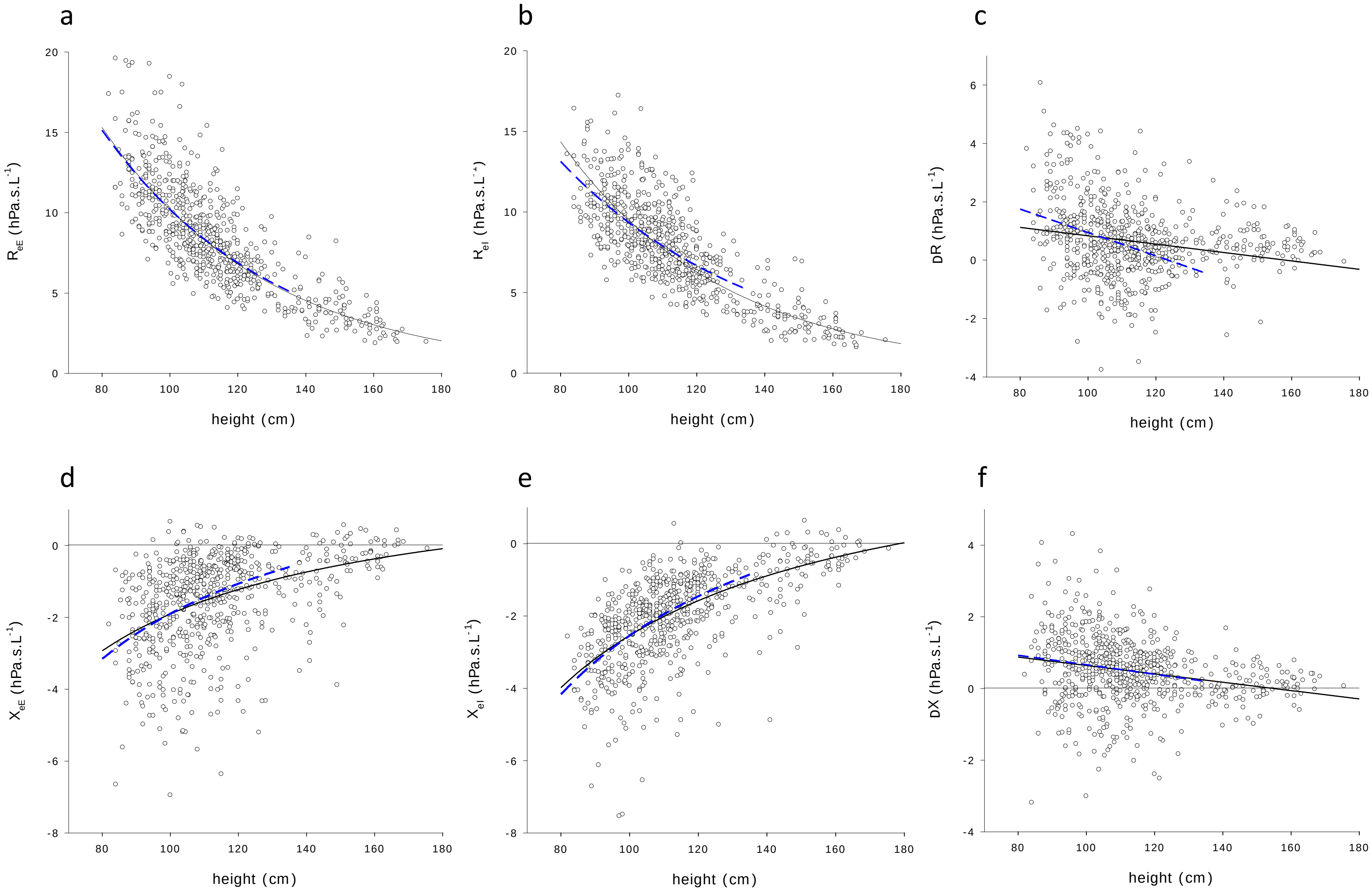

Figure S3: Intra-breath oscillometry measures ~~measures~~ vs height: a) resistance at end expiration (R_{eE}) , b) resistance at end inspiration (R_{eI}), c) tidal change in resistance $\Delta R=R_{eE}-R_{eI}$, d) reactance at end expiration (X_{eE}), e) reactance at end inspiration (X_{eI}) and f) tidal change in reactance ($\Delta X=X_{eE}-X_{eI}$). Solid and dashed lines, respectively, indicate prediction equations for the 3-17-yr and 3-7-yr ranges.

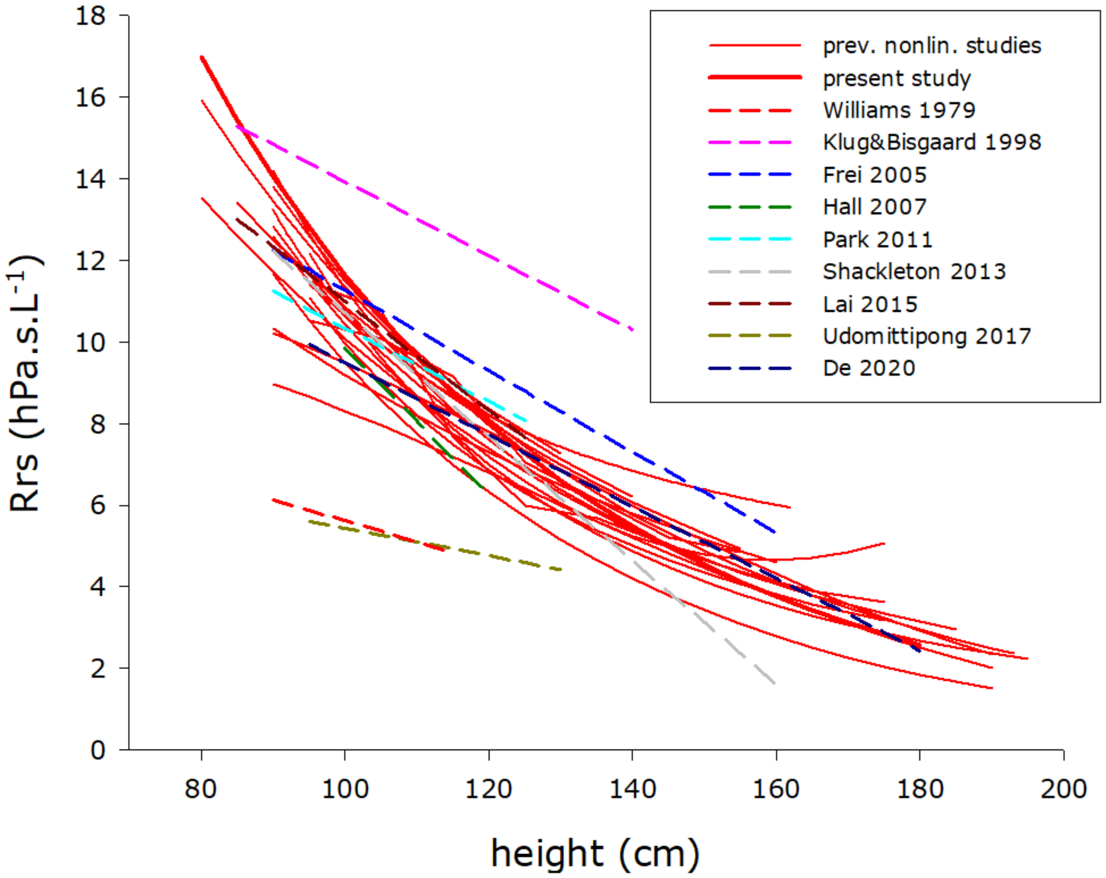

Figure S4: Comparison of respiratory resistance (Rrs) *vs* height (Ht) relationships with previous studies using linear regression between Rrs and Ht (see References). For the individual studies reporting nonlinear Rrs vs Ht relationships, see Figure 2 in the main document.

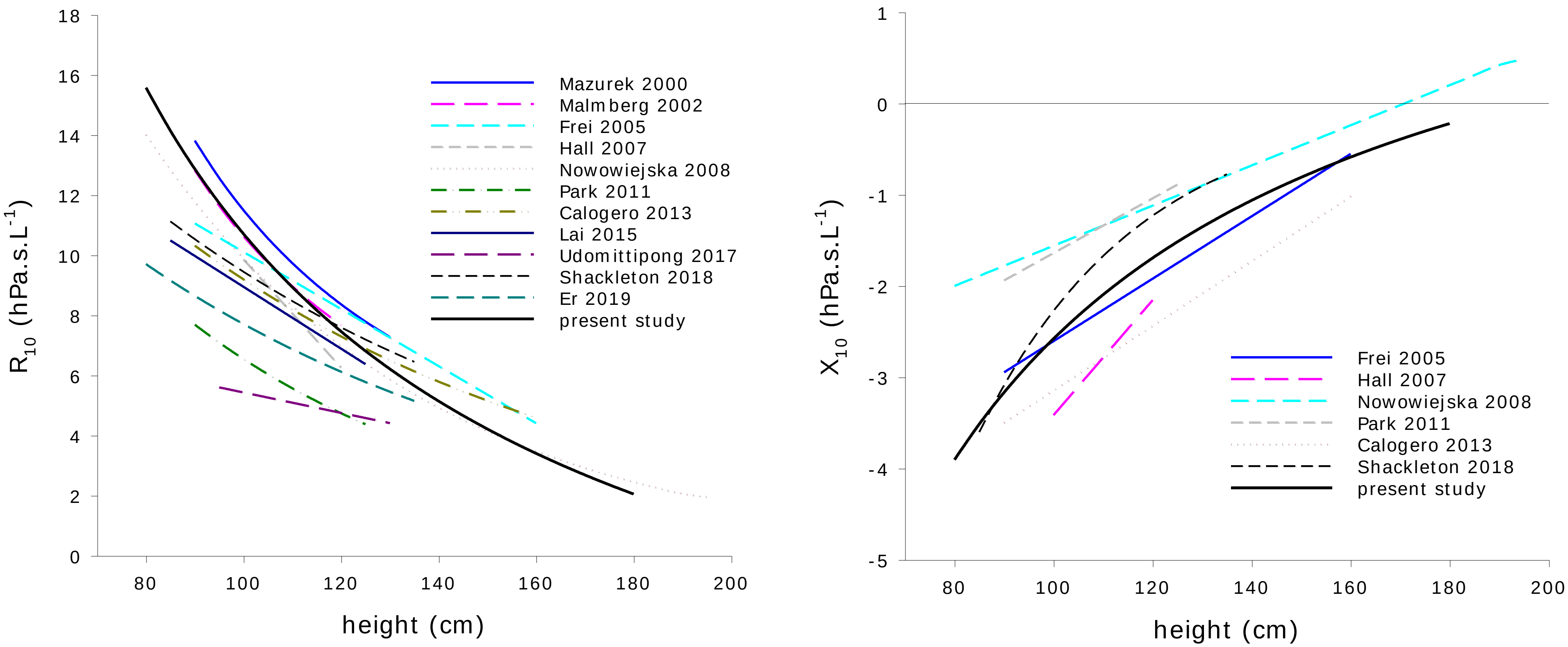

Figure S5: Comparison of at 10-Hz resistance (R_{10}, left) and reactance (X_{10}, right) *vs* height (Ht) relationships with previous studies (see References).

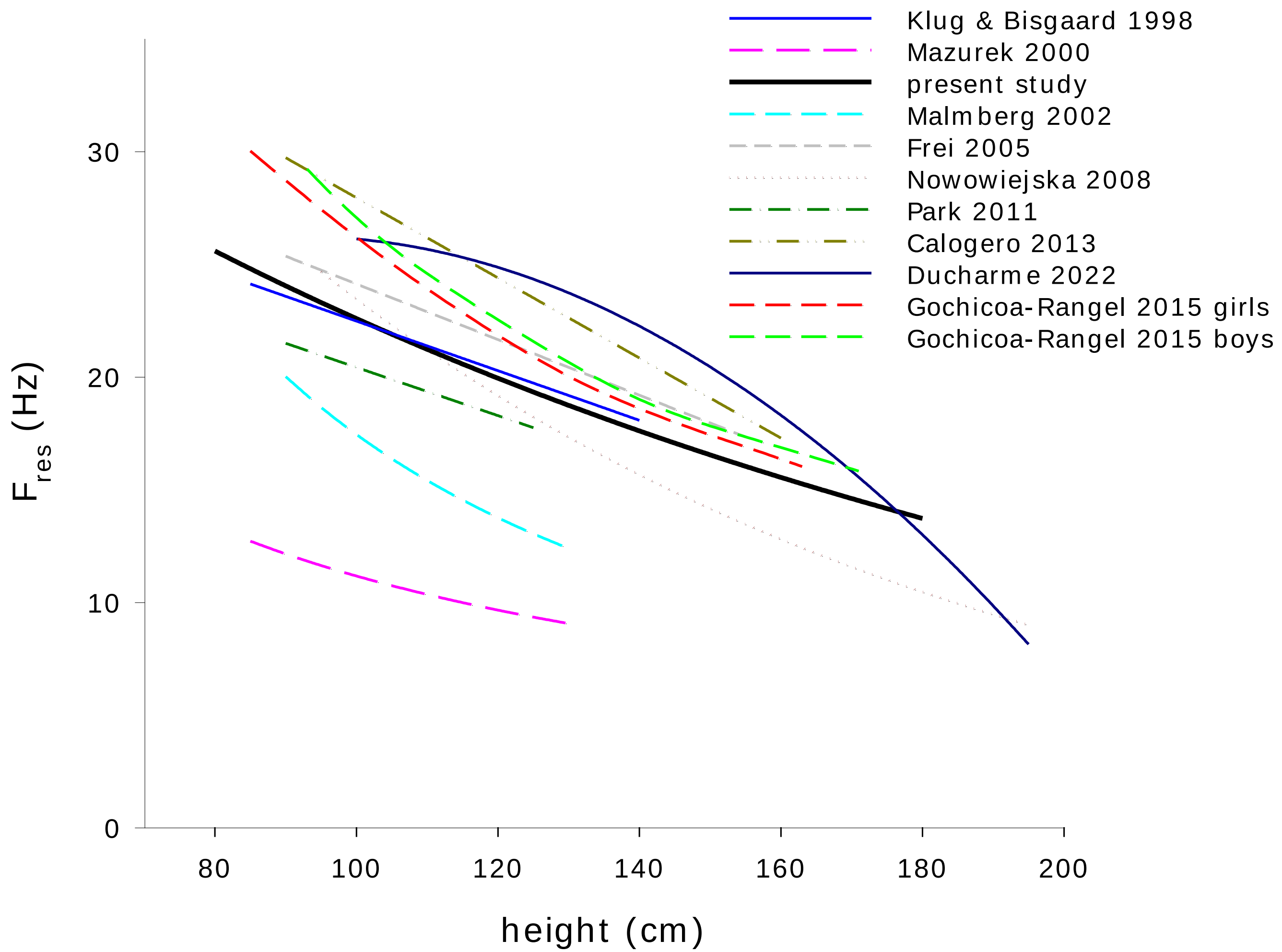

Figure S6: Comparison of resonance frequency (F_{res}) *vs* height (Ht) relationships with previous studies (see References).

Table S5 : Summary of reference studies on resistance (R) vs height (Ht) relationships

Author(s) [ref]	year	frequency (Hz)	device	country/race	no. of subjects	age range (yr)	reference equation	units (Zrs; Ht)
Mansell et al. [1]	1972	5	custom made	Canada	79	3-17	R5=exp(1.877-0.0089·Ht)	$cmH_2O.s.L^{-1}$; cm
Cogswell [2]	1973	5-7	custom made	UK	204	3-12	R5-7 *vs* Ht range data	$cmH_2O.s.L^{-1}$; cm
Stanescu et al. [3]	1979	4-9	custom made	Belgium	130	3-14	R4 *vs* Ht range data	$cmH_2O.s.L^{-1}$; cm
Solymar et al. [4]	1985	2-12	custom made	Sweden	218	2-18	R4=antilog(1.053-2.18·log(Ht))	$kPa.s.L^{-1}$; m
Hordvik et al. [5]	1985	2-26	custom made	USA/C	138	2-16	$R6=9.2\cdot Ht^2-34.1\cdot Ht+35.2$	$cmH_2O.s.L^{-1}$; cm
Hantos et al. [6]	1985	3-10	custom made	Hungary	121	4-16	$R(3\text{-}10)=1.28\cdot 10^5\cdot Ht^{-2.05}$	$cmH_2O.s.L^{-1}$; cm
Duiverman et al. [7]	1985	2-26	custom made	The Netherlands/C	255	2.3-12.5	$R6=0.0017\cdot Ht^2-0.541\cdot Ht+47.73$	$cmH_2O.s.L^{-1}$; cm
Ducharme et al. [8]	1998	8-16	Custo Vit R	Canada/mixed	199	3-17	R8=exp(10.99-2.37·ln(Ht))	$kPa.s.L^{-1}$; cm
Mazurek et al. [9]	2000	4-32	custom made	Poland	127	2.5-7.5	R6=exp(2.4422-1.7447·ln(Ht))	$hPa.s.L^{-1}$; m
Malmberg et al.[10]	2002	5-35	Jaeger IOS	Finland	109	2-7	R5=exp(2.115-1.786·ln(Ht))	$kPa.s.L^{-1}$; cm
Dencker et al. [11]	2006	5-35	Jaeger IOS	Finland-Sweden/C	360	2-11	R5 *vs* Ht curve	$kPa.s.L^{-1}$; cm
Nowowiejska et al. [12]	2008	5-35	Jaeger IOS	Poland	626	3-18	R5=exp(-0.0169·Ht+1.818)	$kPa.s.L^{-1}$; cm
Calogero et al. [13]	2013	4-48	Chess i2M	Australia-Italy/C	760	2-13	R6=exp(3.3738-0.01155·Ht)	$hPa.s.L^{-1}$; cm
Shackleton et al. [][14]	2018	6-26	custom made**	Australia/Hungary	319	3-6	R6= exp(3.3501-0.01033·Ht)	$hPa.s.L^{-1}$; cm
AlBlooshi et al. [15]	2018	5-37	tremoflo C-100	UAE/Emirati	291	4-12	R5=exp(3.786-0.014·Ht)	$cmH_2O.s.L^{-1}$; cm
Er et al. [16]	2019	5-35	Jaeger IOS	Turkey/Turkish	151	3-7	R5=antilog(0.527-0.005·Ht)	$kPa.s.L^{-1}$; cm
Ducharme et al. [17]-1	2022	5-37	Resmon Pro	Canadian/mixed	271	3-17	$R5=\exp(-0.1509+0.00809\cdot Ht-0.0000824\cdot Ht^2)$	$kPa.s.L^{-1}$; cm
Ducharme et al. [17]-2	2022	5-37	tremoflo C-100	Canadian/mixed	292	3-17	$R5=\exp(-0.0252+0.00809\cdot Ht-0.0000817\cdot Ht^2)$	$kPa.s.L^{-1}$; cm
Frei et al. [18]	2005	5-35	Jaeger IOS	Canada	222	3-10	R5=2.117-0.0099·Ht	$kPa.s.L^{-1}$; cm
Hall et al. [19]	2007	4-48	Chess i2M	Australia	149	2-7	R6=27.86-0.18·Ht	$hPa.s.L^{-1}$; cm
Park et al. [20]	2011	5-35	Jaeger IOS	Korea/Korean	133	3-6	R5=1.934-0.009·Ht	$kPa.s.L^{-1}$; cm
Shackleton et al. [21]	2013	4-48	Chess i2M	Mexico/Mexican	584	3-5	R6=25.918-0.152·Ht	$hPa.s.L^{-1}$; cm
Lai et al. [22]	2015	5-35	Jaeger IOS	Taiwan/Taiwanese	150	2-6	R5=2.4395-0.0134·Ht	$kPa.s.L^{-1}$; m
Udomittipong et al. [23]	2017	4-48	Quark i2M	Thailand/Thai	233	3-7	R6=8.834-0.034·Ht	$hPa.s.L^{-1}$; cm
De et al. [24]	2020	5-19	Resmon Pro	India/Indian	159	5-17	R5=18.683-0.09·Ht (boys)	$cmH_2O.s.L^{-1}$; cm

Nonlinear and linear predictions; C: Caucasian

<u>Online reference tool: See attached excel document**</u>**

References

1. Mansell A, Levison H, Kruger K, et al. Measurement of Respiratory Resistance in Children by Forced Oscillations. American Review of Respiratory Disease. 1972;106(5):710-4.
2. Cogswell J. Forced oscillation technique for determination of resistance to breathing in children. Archives of Disease in Childhood. 1973;48(4):259-66.
3. Stănescu D, Moavero NE, Veriter C, et al. Frequency dependence of respiratory resistance in healthy children. J Appl Physiol Respir Environ Exerc Physiol. 1979;47(2):268-72.
4. Solymar L, Aronsson PH, Sixt R. The forced oscillation technique in children with respiratory disease. Pediatr Pulmonol. 1985;1(5):256-61.
5. Hordvik NL, König P, Morris DA, et al. Normal values for forced oscillatory respiratory resistance in children. Pediatric Pulmonology. 1985;1(3):145-8.
6. Hantos Z, Daróczy B, Gyurkovits K. Total respiratory impedance in healthy children. Pediatr Pulmonol. 1985;1(2):91-8.
7. Duiverman E, Clement J, Van de Woestijne K, et al. Forced oscillation technique. Reference values for resistance and reactance over a frequency spectrum of 2-26 Hz in healthy children aged 2.3-12.5 years. Bulletin Europeen de Physiopathologie Respiratoire. 1985;21(2):171-8.
8. Ducharme FM, Davis GM, Ducharme GR. Pediatric reference values for respiratory resistance measured by forced oscillation. Chest. 1998;113(5):1322-8.
9. Mazurek H, Willim G, Marchal F, et al. Input respiratory impedance measured by head generator in preschool children. Pediatr Pulmonol. 2000;30(1):47-55.
10. Malmberg La, Pelkonen A, Poussa T, et al. Determinants of respiratory system input impedance and bronchodilator response in healthy Finnish preschool children. Clinical physiology and functional imaging. 2002;22(1):64-71.
11. Dencker M, Malmberg LP, Valind S, et al. Reference values for respiratory system impedance by using impulse oscillometry in children aged 2-11 years. Clinical Physiology and Functional Imaging. 2006;26(4):247-50.
12. Nowowiejska B, Tomalak W, Radliński J, et al. Transient reference values for impulse oscillometry for children aged 3-18 years. Pediatr Pulmonol. 2008;43(12):1193-7.
13. Calogero C, Simpson SJ, Lombardi E, et al. Respiratory impedance and bronchodilator responsiveness in healthy children aged 2-13 years. Pediatr Pulmonol. 2013;48(7):707-15.
14. Shackleton C, Czovek D, Grimwood K, et al. Defining 'healthy'in preschool-aged children for forced oscillation technique reference equations. Respirology. 2018;23(4):406-13.
15. AlBlooshi A, AlKalbani A, Narchi H, et al. Respiratory function in healthy Emirati children using forced oscillations. Pediatric pulmonology. 2018;53(7):936-41.
16. Er I, Gunlemez A, Baydemir C, et al. Impulse oscillometry reference values and correlation with predictors in Turkish preschool children. Turkish Journal of Pediatrics. 2019;61(4):560-7.
17. Ducharme FM, Smyrnova A, Lawson CC, et al. Reference values for respiratory sinusoidal oscillometry in children aged 3 to 17 years. Pediatr Pulmonol. 2022;57:2092-2102
18. Frei J, Jutla J, Kramer G, et al. Impulse oscillometry: reference values in children 100 to 150 cm in height and 3 to 10 years of age. Chest. 2005;128(3):1266-73.
19. Hall GL, Sly PD, Fukushima T, et al. Respiratory function in healthy young children using forced oscillations. Thorax. 2007;62(6):521-6.
20. Park JH, Yoon JW, Shin YH, et al. Reference values for respiratory system impedance using impulse oscillometry in healthy preschool children. Korean journal of pediatrics. 2011;54(2):64.
21. Shackleton C, Barraza-Villarreal A, Chen L, et al. Reference ranges for Mexican preschool-aged children using the forced oscillation technique. Archivos de Bronconeumología (English Edition). 2013;49(8):326-9.
22. Lai S-H, Yao T-C, Liao S-L, et al. Reference Value of Impulse Oscillometry in Taiwanese Preschool Children. Pediatrics and neonatology. 2015;56(3):165-70.
23. Udomittipong K, Srisukhon W, Nimmannit A, et al. Respiratory impedance reference values for forced oscillation technique predicted by arm span and height in Thai preschool children. Pediatric allergy, immunology, and pulmonology. 2017;30(2):97-102.
24. De S, Banerjee N, Tiwari RR. Regression Equations of Respiratory Impedance Measured by Forced Oscillation Technique for Indian Children. Indian Journal of Pediatrics. 2020;87(3):192-9.
25. Gochicoa-Rangel L, Torre-Bouscoulet L, Martínez-Briseño D, et al. Values of impulse oscillometry in healthy Mexican children and adolescents. Respiratory Care. 2015;60(1):119-27.