Reference values for respiratory system impedance by using impulse oscillometry in children aged 2-11 years

M. Dencker [1], L. P. Malmberg [2], S. Valind [1], O. Thorsson [1], M.K. Karlsson [1], A. Pelkonen [2], A. Pohjanpalo [3], T. Haahtela [2], M. Turpeinen [2], P. Wollmer [1]

1) Dept of Clinical Sciences, Malmö, Lund University, Sweden
2) Dept of Allergy, Helsinki University Hospital, Helsinki, Finland
3) Espoo Social and Healt Care Center, Espoo, Finland

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Corresponding author:

Magnus Dencker

Dept of Clinical Sciences, Malmö

Clinical Physiology and Nuclear Medicine unit

University Hospital MAS

205 02 Malmö, Sweden

E-mail: magnus.dencker@skane.se

Phone: +46 40-338731

Fax +46 40-338768

Summary

The forced oscillation technique makes it possible to evaluate the mechanical properties of the respiratory system with a minimum of cooperation. The method is therefore especially useful in children. Impulse oscillometry (IOS) is a commercially available version of this technique. There is, as yet, limited information on reference values for IOS in children. The aim of this study was to extend the reference values for IOS variables and to study their correlation with height, weight and age in healthy children. A sample (n = 360) of children (age 2.1-11.1 years) was measured by using impulse oscillometry (IOS Jaeger, Würzburg, Germany). The sample was based on children attending kindergarten in Finland and children attending primary school in Sweden. Measurements of respiratory resistance (Rrs) and reactance (Xrs) at 5, 10, 15, and 20 Hz, total respiratory impedance (Zrs) and the resonance frequency (Fr) were made. All variables were related to body height. Most of them were also weakly related to weight. Reference equations for children (height 90-160 cm) are presented.

Key words: Children; forced oscillation; reference values; respiratory function tests; respiratory resistance.

Introduction

The forced oscillation technique (FOT) (Solymar et al., 1989; Oostveen et al., 2003) makes it possible to evaluate the mechanical properties of the respiratory system with a minimum of co-operation. This makes the technique suitable for use in young children who may have difficulty co-operating during a traditional spirometric examination. Another advantage of measurements made during tidal breathing is that the forced breathing manoeuvres performed at conventional spirometry may themselves affect bronchial tone (Weersink et al., 1995; Pellegrino et al., 1996). Furthermore, with FOT, more specific information of the resistive and elastic properties of the respiratory system can be obtained than is possible by spirometric measurements. FOT may therefore be useful also in older children and in adults. Impulse oscillometry (IOS) is a commercially available modification of the FOT (IOS, Jaeger, Würzburg, Germany) (Vogel & Smidt, 1994). IOS uses rectangular pulse-flow signals as input for measurement of input impedance. IOS and other modifications of FOT have been used for assessing the mechanical properties of the respiratory system in children with astma (König et al., 1984; Solymar et al 1985; Duiverman et al., 1986; Lebecque et al., 1987; Bisgaard & Klug, 1995; Klug & Bisgaard, 1996; Lebecque & Stanescu,1997; Hellinckx et al., 1998 a), cystic fibrosis (Solymar et al 1985 a; Lebecque & Stanescu,1997; Hellinckx et al., 1998 b Malmberg et al 2003) and chronic lung disease caused by prematurity (Duiverman et al., 1988; Malmberg et al., 2000). FOT has also been used to measure changes during bronchodilator tests (Delacourt et al., 2000; Malmberg et al., 2002). Reference values for IOS (Klug & Bisgaard, 1998; Hellinckx et al., 1998 a; Malmberg et al., 2002; Mazurek et al., 2000; Frei et al., 2005) as well as for other modifications of FOT (Mansell et al., 1972; Clement et al., 1983; Duiverman et al., 1985; Solymar et al 1985 b), have been published. Only limited information is available in children above the age of seven (height >130 cm). The primary aim of this study was to create comprehensive reference values of determinants of respiratory system impedance using IOS in healthy children aged 2-11 years. The secondary aim was to study changes in the mechanical properties of the respiratory system during growth in a cross-sectional analysis.

Material and methods

Subjects

The subjects for this study come from two different populations. The Finnish group (n=109, age 2.1-7.0 years) was recruited among children attending kindergartens in Espoo, Finland. Selection procedure and results from this group have been published previously (Malmberg et al., 2002). The inclusion criteria were identical to the criteria described for the Swedish group. Skin prick tests for common allergens were performed in the Finnish group and subjects with positive tests were excluded. This was not done in the Swedish group.

The Swedish group (n=251, age 7.0–11.1 years) was recruited among children attending four different schools in Malmö, Sweden. Five hundred and one children received an invitation to participate. 268 accepted the invitation. The definition of the GAP conference (Taussig et al., 1980) for healthy children was used. Children were considered eligible for the study if they were of Caucasian origin. A questionnaire was used to exclude asthma or allergic disorders. Children that were included had no present acute and no past or present chronic disease of the respiratory tract, and no history of upper respiratory tract infection during the two weeks prior to the investigation. Of the 268 children that accepted to participate in the study 17 were excluded. Fifteen children were excluded because of a history of asthma or allergy. Two children were excluded because of current illness. Altogether 251 children from the Swedish group were included in the study. Before the oscillometric measurements, the standing height and the weight were measured. Body surface area (BSA) was calculated as (height in cm)$^{0.725}$ x (weight in kg)x$^{0.425}$ x 0.00718 (Du Bois & Du Bois, 1916). The study was approved by the ethics committee of the University of Lund. Written informed consent was obtained from the parents of all participating children.

Oscillometric measurements

The procedure was identical for the two groups of subjects. IOS (Jaeger, Würzburg, Germany) (Vogel & Smidt, 1994) measurements were performed while the subject was seated and breathing quietly. The output pressure and flow signals were analysed for their amplitude and phase difference, to determine the resistance (Rrs) and reactance (Xrs) of the respiratory system, components of the respiratory impedance (Zrs). The impulse interval for IOS measurements was set to 0.3 s, and for each impulse, 32 sample points were analysed. By using fast Fourier transformation, Rrs and Xrs were calculated as a function of the oscillation frequency of 5-20 Hz. The frequency, where the reactance equals zero, is the resonance frequency (Fr). The pneumotachograph of the device was daily calibrated and the system was also checked against a reference impedance of 0.2 kPa l^{-1}s. During the measurement, the flow signal was monitored for signs of swallowing glottis closure and leaks. Measurements were regarded acceptable only when the time segment chosen for analysis was free from artefacts and lasted at least 20 s. From the raw data values for Rrs and Xrs at 5, 10, 15 and 20 Hz and the resonance frequency (Fr) were calculated.

Statistical methods

All calculations were performed in Statistica 5.0 (StatSoft Inc, Tulsa, OK, USA). ANOVA was used to test any existing gender differences. The influence of standing height, ln(height), height^{-3}, age, weight and body surface area on the oscillometric variables was examined by stepwise regression analysis. Finally, the obtained prediction models were compared with those published previously.

Results

The age of the children in the Finnish study group ranged from 2 to 7 years and their height from 90 to 129 cm. The children in the Swedish study group were from 7 to 11 years of age and their height ranged from 118 to 162 cm. In stepwise regression analysis, the height^{-3} was the strongest independent variable for the models of all the oscillometric variables. Only the introduction of weight improved the coefficient of determination in some IOS parameters, other factors such as gender, age, and body surface area had no impact on the models of all the oscillometric variables. Therefore, height^{-3} and weight were used as a predictor in the regression models, with both genders pooled together. The regression models for all the variables have been summarized in Table 1.

Rrs at 5 Hz versus standing height in all children is shown in Fig 1. Regression curves for Rrs at 5 Hz and at 20 Hz are shown in Fig. 2. The reduction in resistance with increasing height at both frequencies can be observed, and that the regression lines obtained are essentially parallel. Xrs at 5 Hz and at 20 Hz are shown in Fig. 3. Xrs at 5 Hz increases with increasing height, but in contrast, Xrs at 20 Hz remains essentially constant over the height range. A comparison of the present and previously published regression equations for Rrs at 5 Hz using the IOS technique is illustrated in Fig. 4.

Discussion

In this study, we combine measurements made in two groups of normal children in Finland and in Sweden. The Finnish and Swedish populations are closely related, and the inclusion criteria in the two studies were identical. The Finnish children were recruited from kindergartens and the Swedish children from primary schools. We therefore consider the two groups comparable in all respects but age. The IOS measurements were made in the same way, with identical equipment, in both groups, and there was some overlap in body height. The results in the overlapping part of the material were identical in the Finnish and the Swedish children, indicating that the measurements at the two sites are comparable. Owing to the larger number of Swedish children, there are slightly more observations in the height interval 130-145 cm.

Standing height was the main antropometric determinant of the oscillometric results, which is in agreement with previous studies (Mansell et al., 1972; Clement et al., 1983; Duiverman et al., 1985; Solymar et al 1985 b; Klug & Bisgaard, 1998; Hellinckx et al., 1998 a; Mazurek et al., 2000; Malmberg et al., 2002; Frei et al., 2005). In agreement with most previous observations, no significant gender related difference was found for respiratory resistance. Only one study has reported higher resistance in males up to 8 years of age (Duiverman et al., 1985).

Three paediatric reference samples have previously been published using IOS (Klug & Bisgaard, 1998; Hellinckx et al., 1998 a; Frei et al., 2005). Only one of these include children above the age of seven (height >130 cm) (Frei et al., 2005). Our reference values are close to those reported by Hellinckx et al. and Frei et al., where as Klug and Bisgaard found higher resistance and lower reactance values. The difference may be the influence of a special mask system. Reference values have been published for the pseudorandom noise technique (Solymar et al., 1985 b; Duiverman et al., 1985). The present equation for Rrs5 is close to that of respiratory resistance at 4 Hz by Solymar et al. and agrees also with that by Duiverman et al. in girls; however, in the latter study that included somewhat older children, higher values of resistance in boys were observed. Although pseudorandom noise method and impulse oscillometry give comparable results (Hellinckx et al., 2001), the diversity of measurement techniques probably contribute to differences in reference values. Compared with published data measured by a head generator (Mazurek et al., 2000), the present results of Rrs or Xrs do not differ markedly at low frequencies, but show lower values of Rrs and Xrs at higher frequencies.

When Rrs was analysed at different frequencies and related to height, essentially parallel regression curves were found for the different frequencies (Fig 2). Differences were seen between Xrs at 5 and 20 Hz with increasing height. Xrs at 5 Hz was considerably lower in small children and increased with height, whereas Xrs at 20 Hz was essentially independent of height. As Xrs is a complex variable reflecting both elastic and mass-inertial properties of the respiratory system, the observed difference may arise from various factors. Inertial forces predominate at higher oscillatory frequencies and are dependent on the dimensions of upper airways where large volumes of air are accelerated. At low frequencies, the capacitive component of Xrs reflects peripheral lung compartments: the volume of the peripheral lung units and the compliance of the peripheral lung tissue including the thorax. Whereas all generations of the bronchial tree are formed at birth, the number of alveoli increases during growth (Reid, 1984). The height dependence of Xrs is likely partly to reflect the increasing number of alveoli.

The measurement of respiratory input impedance with the impulse oscillometry has already shown to have clinical value in children with a variety of respiratory disorders. It remains to be seen whether the present extended reference values will further increase the clinical relevance of IOS in measuring respiratory function of children.

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Table 1. Summary of regression equations for IOS variables. Body height (h) in metres and body weight (w) in kilograms.

Regression equation	RSD
$Fr=11.749+4.373*h^{-3}+0.103*w$	3.829
Zrs at 5 Hz=$0.282+0.801*h^{-3}+0.004*w$	0.193
Rrs at 5 Hz=$0.266+0.759*h^{-3}+0.004*w$	0.188
Rrs at 10 Hz=$0.187+0.751*h^{-3}+0.003*w$	0.162
Rrs at 15 Hz=$0.290+0.647*h^{-3}$	0.161
Rrs at 20 Hz=$0.259+0.630*h^{-3}$	0.159
Xrs at 5 Hz= $-0.123-0.225*h^{-3}$	0.090
Xrs at 10 Hz=$0.012-0.107*h^{-3}-0.002*w$	0.067
Xrs at 15 Hz=$-0.049-0.077*h^{-3}-0.001*w$	0.065
Xrs at 20 Hz=$0.113-0.062*h^{-3}-0.001*w$	0.056

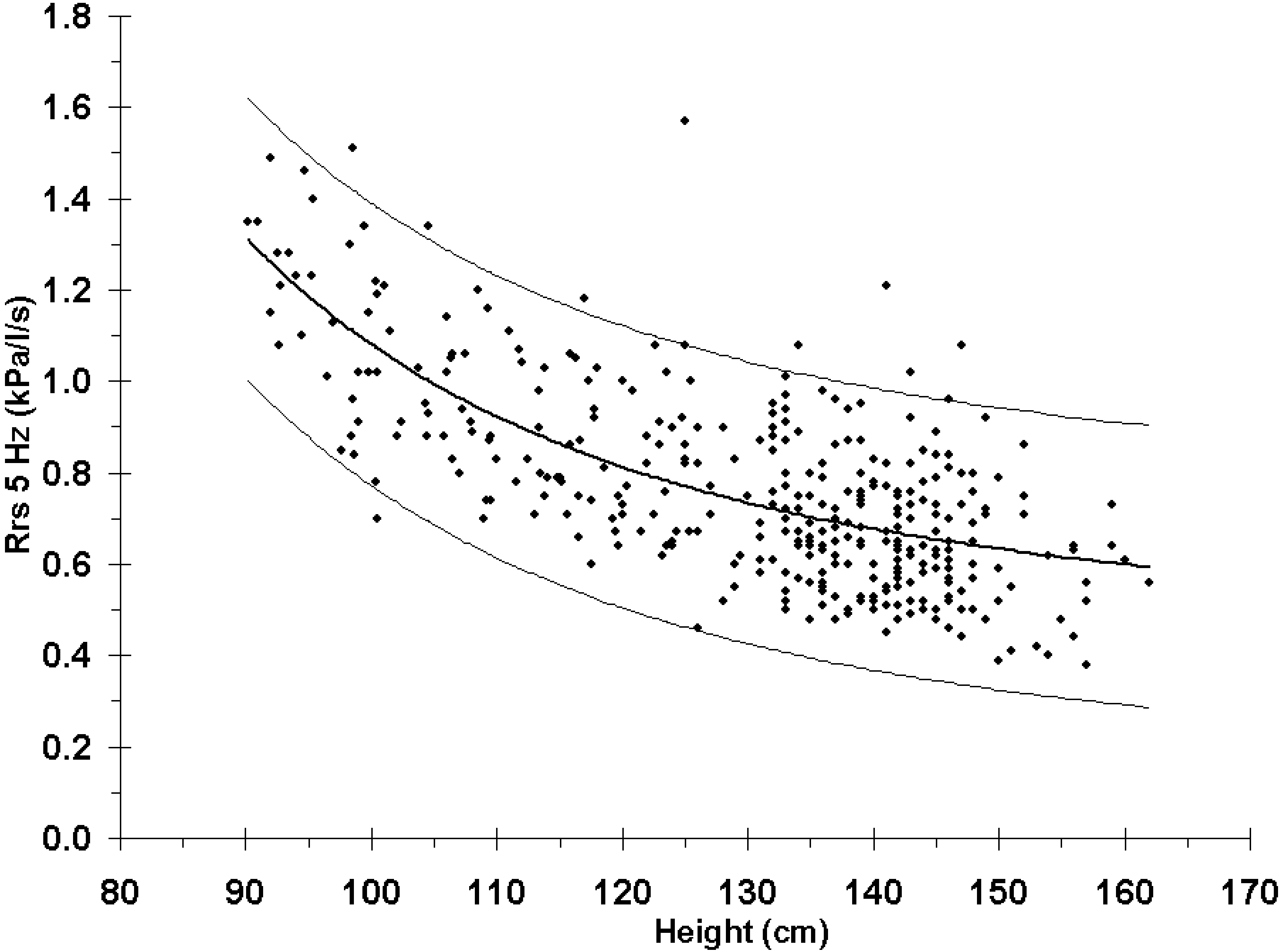
Figure legends:

Fig 1. Display of Rrs at 5 Hz versus height in all children (n=360). Curves are regression curve ± 2 RSD.

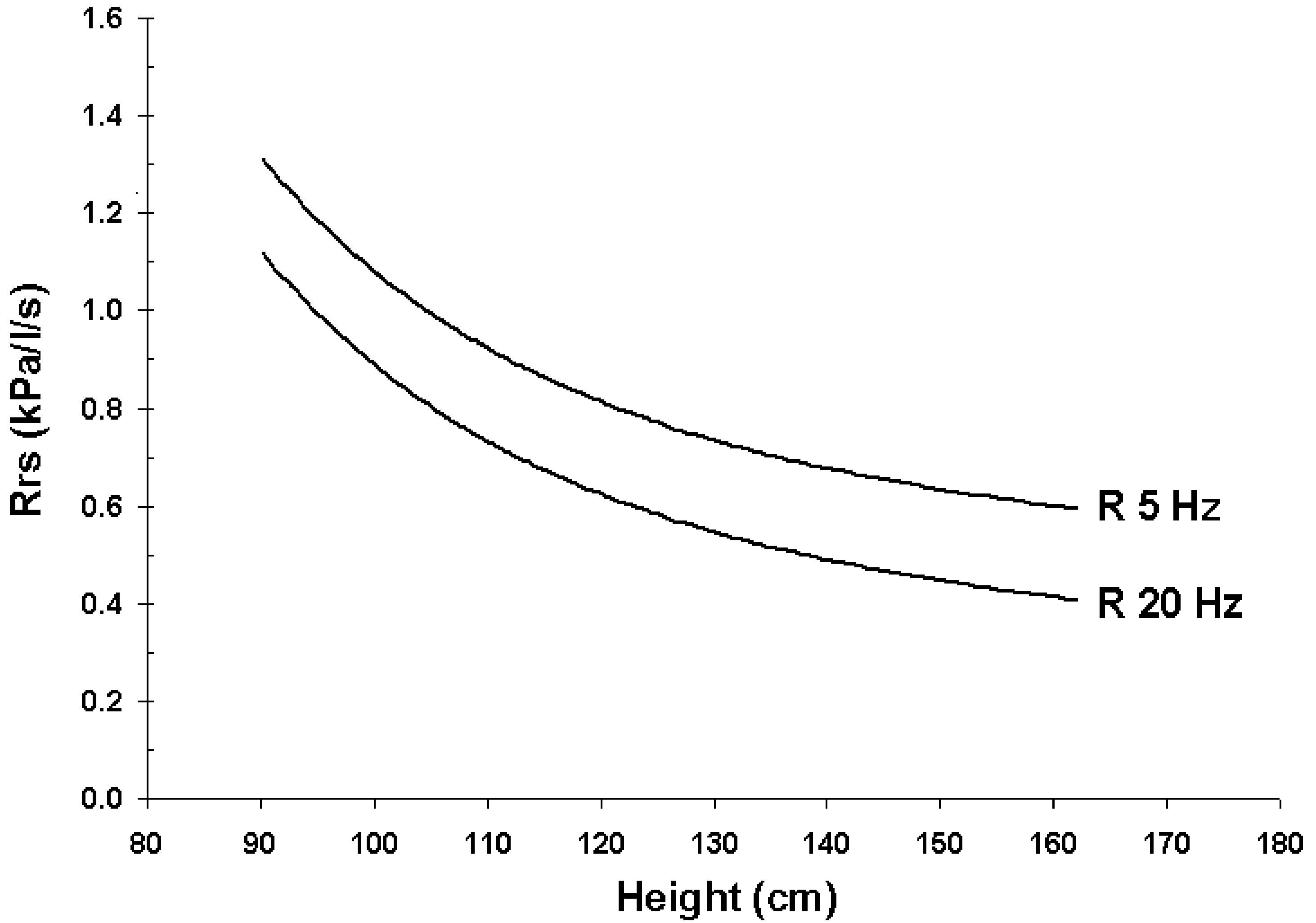
Fig 2. Comparison between Rrs at 5 and 20 Hz in relation to height.

Fig. 3. Comparison between Xrs at 5 and 20 Hz in relation to height.

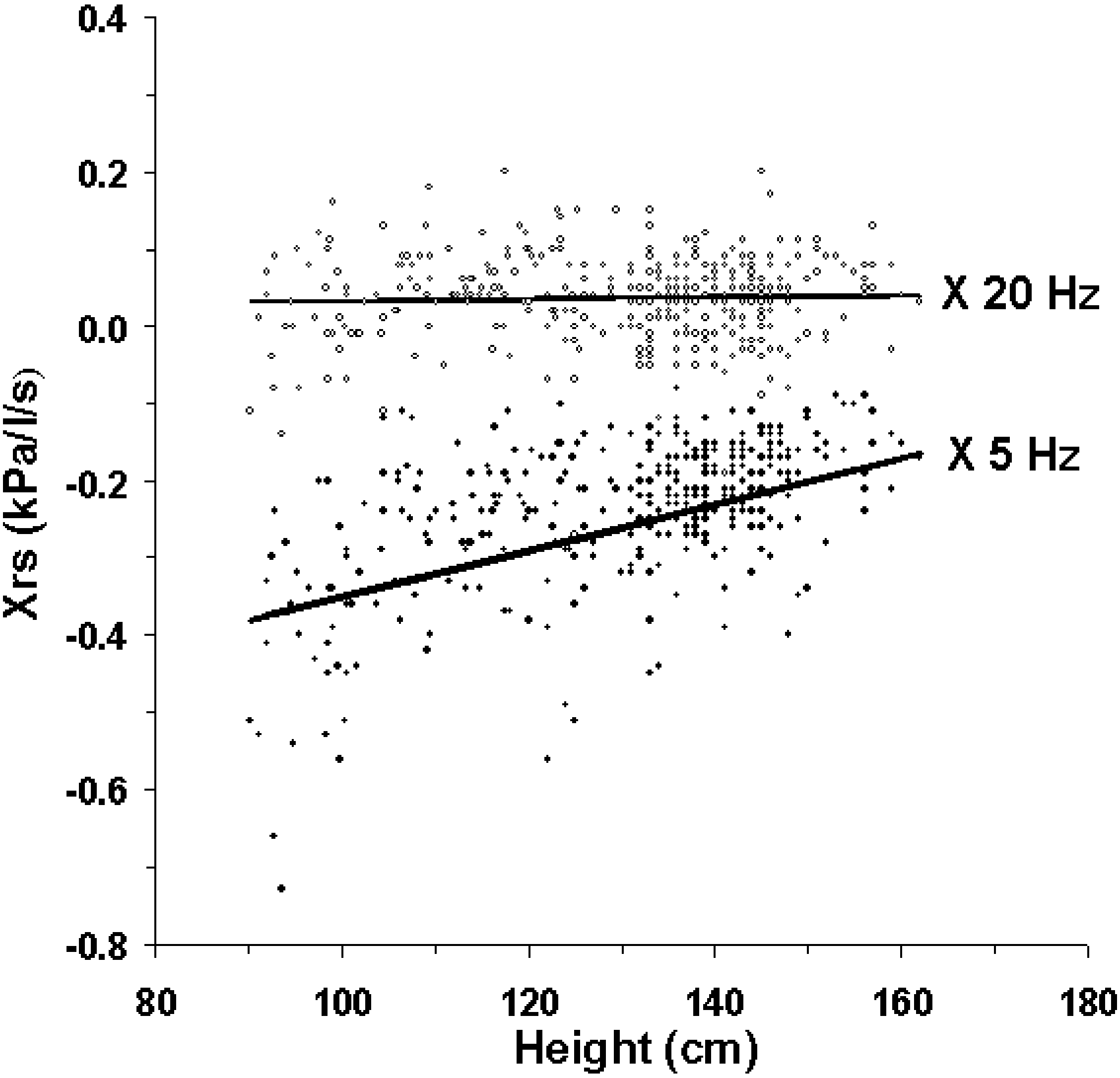
Fig 4. Comparison of reference equations in present study compared with previous studies using IOS.



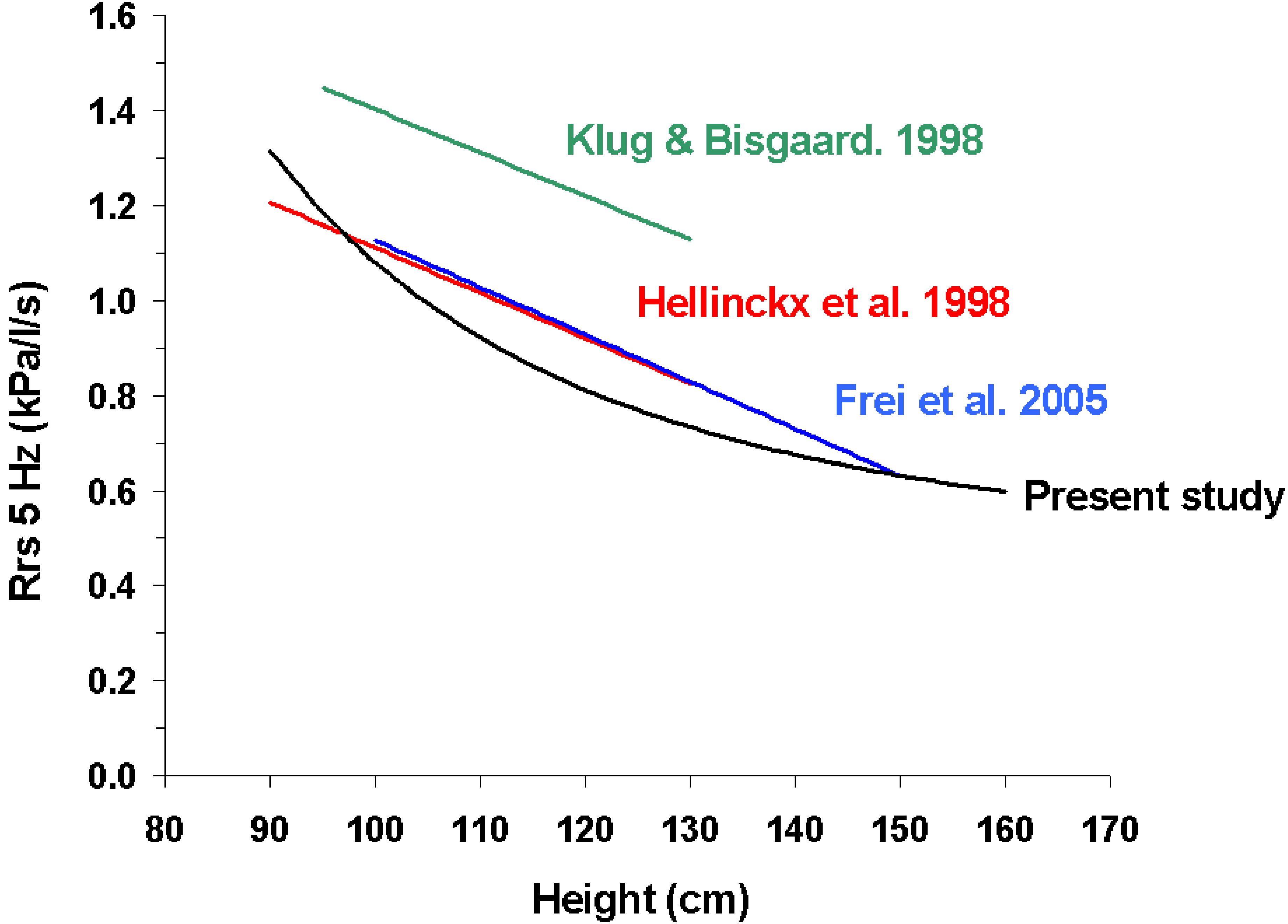
Rrs 5 Hz (kPa/l/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
80
90
100
110
120
130
140
150
160
170
Height (cm)



Rrs (kPa/l/s)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
80
90
100
110
120
130
140
150
160
170
180
Height (cm)
R 5 Hz
R 20 Hz



0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Xrs (kPa/l/s)
X 20 Hz
X 5 Hz
80
100
120
140
160
180
Height (cm)


Rrs 5 Hz (kPa/l/s)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
80
90
100
110
120
130
140
150
160
170
Height (cm)
Klug & Bisgaard. 1998
Hellinckx et al. 1998
Frei et al. 2005
Present study