ORIGINAL ARTICLE

Impact of Obstructive Sleep Apnea on Global Myocardial Performance in Children Assessed by Tissue Doppler Imaging

Gehan Attia · Magda A. Ahmad · Abdel Baset Saleh · Asser Elsharkawy

Abstract This study aimed to assess the impact of obstructive sleep apnea (OSA) due to adenotonsillar hypertrophy (ATH) on the global myocardial performance in children using tissue Doppler imaging (TDI) and to evaluate the reversibility of the disorder after adenotonsillectomy (AT). The study included 42 children with OSA due to ATH (mean age, 5 ± 3.14 years) as the study group and 45 age- and sex-matched healthy children (mean age, 5.2 ± 3.08 years) as the control group. Polysomnography and echocardiography were performed. Indexed left ventricular mass (LVMi), pulmonary artery systolic pressure, mean pulmonary artery pressure (mPAP), and pulmonary vascular resistance (PVR) were calculated by echocardiography. Tissue Doppler imaging was used to determine the left ventricular and right ventricular myocardial performance index (MPI) of patients and control subjects before and after AT. The patients were classified into mild OSA (apnea-hypopnea index [AHI] 1–5; $n = 18$)] and moderate to severe OSA (AHI >5; $n = 24$) according to polysomnography findings. All the children in the control group had an AHI less than 1. They were treated using AT, then reevaluated by polysomnography and echocardiographic examination 6 to 8 months after surgery. Results are described as mean $\pm$ standard deviation. The patients with OSA had higher pulmonary artery systolic pressure, mPAP, PVR, LVMi, and right ventricular diastolic diameter than the control subjects. The patients with moderate to severe OSA showed more prominent changes than the patients with mild OSA, but the latter still differed significantly from the control subjects. The TDI-derived right ventricular MPI and left ventricular MPI measurements of the patients with OSA were higher (mean, 0.40 ± 0.08 vs 0.28 ± 0.01; $p < 0.001$) than those of the control subjects and (0.45 ± 0.05 vs 0.32 ± 0.05; $p < 0.001$) and correlated well with AHI and mPAP. In addition, mPAP was significantly correlated with AHI. Postoperatively, relief of OSA was validated by polysomnography, and a repeat of the echocardiographic parameters showed no significant differences between the patients and the control subjects. Tissue Doppler imaging can detect the subtle, subclinical changes in cardiac performance that occur in OSA due to adenotonsillar hypertrophy. Such changes generally are reversible after surgical treatment.

Keywords Children · Myocardial performance · Obstructive sleep apnea · Tissue Doppler imaging

G. Attia (✉)
Pediatrics Department (Pediatric Cardiology Unit), Faculty of Medicine, Mansoura University, Mansoura 35516, Egypt
e-mail: gehan_sawah@yahoo.com

M. A. Ahmad · A. B. Saleh
Chest Medicine Department (Sleep Disordered Breathing Unit), Faculty of Medicine, Mansoura University, Mansoura 35516, Egypt

A. Elsharkawy
ENT Department, Faculty of Medicine, Mansoura University, Mansoura 35516, Egypt

Obstructive sleep apnea (OSA) is estimated to occur for approximately 2% of children [4]. The frequency of snoring among children is much higher (8–27%) [18, 46]. Obstructive sleep apnea occurs when the upper airway collapses or significantly reduces its luminal cross-sectional area during inspiration [13].

Adenotonsillar hypertrophy (ATH) is the most common cause of OSA in children [61]. Polysomnography (PSG) is considered to be the most useful diagnostic test for evaluating the severity of OSA in children [41]. Obstructive

sleep apnea is associated with cardiopulmonary dysfunction primarily due to the associated hypercapnia, hypoxemia, and pulmonary artery vasoconstriction [30, 31].

Cardiovascular alterations that occur in children with OSA include altered arterial blood pressure regulation [7], systemic hypertension [25] and changes in left ventricular (LV) geometry [6, 8]. Cor pulmonale, developmental delay, failure to thrive, and even death may occur for children with extremely severe OSA [14]. Detection of subclinical myocardial changes is difficult to achieve using conventional techniques that merely evaluate global systolic and diastolic function. Tissue Doppler imaging (TDI) echocardiographic evaluation can detect systolic and diastolic myocardial dysfunction by measuring the myocardial performance index, which is a powerful and sensitive diagnostic and prognostic indicator [33, 34, 54].

Traditionally, adenotonsillectomy (AT) has been the treatment of choice for children with OSA due to ATH. Findings have shown AT to improve PSG results [43], relieve symptoms in the majority of cases, and improve the quality of life experienced by children with OSA [59].

This study aimed to assess the impact of OSA due to ATH on global myocardial performance in children using TDI and to evaluate the potential reversibility of this condition after AT.

Subjects and Methods

This prospective study was conducted in the Pediatric Cardiology Unit of the Children's Hospital and both the Chest Department and the ENT (ear, nose, and throat) Department of Mansoura University between January 2008 and September 2009. Written informed consent was obtained from all parents of the children included in the study, which was approved by the Institutional Review Board of the Children's Hospital of Mansoura University.

The study enrolled 42 children with OSA due to ATH including 26 boys (61.9%) and 16 girls (38.09%) with a mean age of 5 ± 3.14 years. A control group of 45 age- and sex-matched children without OSA symptoms also were included in the study. They were selected from among the siblings of the patients treated in the ENT department. The control subjects who agreed to participate in the study showed no evidence of obstruction at ENT examination and an apnea-hypopnea index (AHI) less than 1 confirmed by home PSG. The control group consisted of 24 boys (53.33%) and 21 girls (46.66%) with a mean age of 5.2 ± 3.08 years.

The exclusion criteria ruled out infants younger than 2 years; obesity (body mass index [BMI] ≥ 30 kg/m^2); congenital or acquired heart disease; central apnea; OSA associated with other medical disorders including but not

limited to Down syndrome, craniofacial anomalies, neuromuscular disease (including cerebral palsy), chronic lung disease, sickle-cell disease, metabolic disease, and laryngomalacia; recent upper airway infection within the preceding 4 weeks; primary snoring and an apnea hypopnea index less than 1. Patients with life-threatening OSA who presented with cardiorespiratory failure also were excluded from the study because they required urgent treatment.

The weight and height of the patients were measured, and their BMI was calculated. Blood pressure measurements were obtained with the patient at rest. Blood pressure was measured twice 10 min apart, and the average was used.

All the studied groups underwent ENT examination, which included nasal and nasopharyngeal endoscopy. All the patients underwent lateral x-rays of the skull to evaluate their air column. Tonsillar hypertrophy was graded according to the Brodsky [12] scale as grade 1 (tonsils in the tonsillar fossa, barely visible behind the anterior pillars), grade 2 (tonsils visible behind the anterior pillars), grade 3 (tonsils extended three-fourths of the way to the midline), and grade 4 (tonsils completely obstructing the airway). Adenoid hypertrophy was graded according to severity of airway obstruction as grade 1 (<25%), grade 2 (25–50%), grade 3 (50–75%), and grade 4 (>75%) airway obstruction [29].

Echocardiography

Echocardiography was performed using the SONOS-5500 device (Hewlett-Packard, Andover, MA, USA) and an 8-MHz probe. Transthoracic echocardiography was performed by an experienced pediatric cardiologist blinded to the ENT and PSG data of the study groups 24 to 48 h after completion of PSG. Echocardiography was performed with the patients at rest in the supine position. Conventional echocardiography was performed according to the American Society of Echocardiography guidelines [40, 49]. The views recorded were the parasternal long axis, parasternal short axis, apical two chamber, and apical four-chamber views.

Two-dimensional, M-mode measurements were obtained to assess right ventricular diastolic diameter (RVDd), left atrial diameter (LA), left ventricular end diastolic diameter (LVIDd), left ventricular end systolic diameter (LVIDs), and fractional shortening of the LV (FS%). Left ventricular mass (LVM) was calculated using Devereux's formula [21, 22] and divided by the subject's height raised to the power of 2.7, as described by de Simone et al. [20], to determine the indexed LV mass (LVMi).

Pulsed-wave Doppler (PWD) echocardiography was used to measure the mitral and tricuspid peak early filling (E-wave), atrial contractility (A-wave), and E/A ratio [44].

The pulmonary artery systolic pressure (PASP) was estimated from the peak tricuspid regurgitation velocity (TRV) (m/s). The highest velocity obtained from multiple measures was used. We used Bernoulli's equation ($P = 4 V^2$) (P: pressure, V: velocity) to calculate the PASP. An estimated right atrial pressure was not added because right atrial pressure is variable, and the addition of an assumed right atrial pressure of 5 mmHg did not significantly alter the results [26]. The mean pulmonary artery pressure (mPAP) was calculated by pulmonary flow tracing using Mahan's formula (mPAP [mmHg] = 79 – [0.62 × Act]), where Act is the acceleration time of the pulmonary flow trace or the interval between the beginning of flow and its peak velocity] [19]. The right ventricular outflow tract velocity time integral (TVI_{RVOT}) in centimeters was obtained by placing a 1 to 2 pulsed-wave Doppler sample volume in the proximal right ventricular outflow tract (RVOT) just within the pulmonary valve in the parasternal short axis view. The pulmonary vascular resistance (PVR) then was calculated using the equation: $PVR = 10 \times (TRV/TVI_{RVOT}) + 0.16$ [2].

Tissue Doppler imaging was performed using a special software package available for use with the SONOS 5500 device. The sample volume was placed at the lateral margin of the mitral and tricuspid annuli on the apical four-chamber view. Tissue Doppler imaging was performed by adjusting the spectral pulsed Doppler signal to obtain a Nyquist limit of 15 to 20 cm/s and by using the minimal optimal gain. High-frame-rate images (>150 frame/s) were acquired in TDI mode. Three consecutive images were recorded. The mean values of these measurements were used for statistical analysis. Right and left ventricular myocardial function was assessed during both contraction and relaxation. Using the four-chamber view, sample volume was placed at the lateral side of the mitral annulus and the RV free wall at the tricuspid annulus. The systolic myocardial velocity (Sm), the early diastolic myocardial velocity (Em), the late diastolic myocardial velocity (Am) at the time of atrial contraction, and the Em/Am ratio of each segment were determined. On TDI, the interval from the end to the onset of the mitral (or tricuspid) annular velocity pattern during diastole (a) were equal to the sum of the isovolumic contraction time (ICT), isovolumic relaxation time (IRT), and ejection time (ET). The ET (b) was measured as the duration of the Sm wave. Next, the myocardial performance index (MPI) was calculated as follows: (a − b)/b or (ICT + IRT)/ET [33, 34].

In the OSA group, all conventional and TDI echocardiographic parameters were measured at baseline and then reevaluated within 6.4 ± 0.56 months (range, 6–8 months) after AT. Adenotonsillar hypertrophy was performed for all the children in the patient group ($n = 42$). No postoperative complications were observed.

Polysomnography

All the children with OSA included in the study underwent at least two sleep studies: one before AT and another at least 6 months after AT. Parents were asked to explain the sleep study process to their children to relieve their anxiety. Chest physicians well trained in Stony Brook University, Stony Brook, New York; and certified from two boarded physicians explained the study to the parents first and then to the children after the parent had explained it once. The physicians did not wear white coats. A doll was sometimes used to help explain the study to the children. Once electrodes were properly placed and the hookup was completed, the parents were allowed to comfort their children if they were upset.

We used the Embletta portable monitoring device for PSG (Embla, Broomfield, CO), which meets the recommendations of the American Academy of Sleep Medicine Manual (AASM). The device provides diagnostic information regarding nasal airflow, pulse oximetry, heart rate, and patient position and activity. It also has electroencephalogram (EEG) electrodes and two respiratory sensors that use the exact trace respiratory inductive plethysmography (RIP).

In this study, we assessed the presence and severity of both apnea and hypopnea according to the apnea and hypopnea guidelines of the AASM [1]. The AHI was defined as the total number of obstructive apnea or hypopnea episodes that occurred per hour of sleep. The oxygen desaturation index (ODI) was defined as the total number of dips in arterial oxygen saturation exceeding 4% that occurred per hour of sleep. Obstructive sleep apnea was diagnosed if the AHI was ≥1 per hour of sleep. The children were divided into the following groups: control group (AHI <1), mild OSA group (AHI 1–5), and moderate to severe OSA group (AHI >5) [5].

Statistical Analysis

Data entry and analyses were performed using the SPSS statistical package, version 10 (SPSS, Inc., Chicago, IL, USA). The quantitative data are presented as means ± standard deviations. Student's t test was conducted to compare the means of continuous variables of the two different groups. The one-way analysis of variance (ANOVA) procedure was used to compare means and standard deviations of more than two groups, and the post hoc test was used to determine whether significant differences existed between the different groups. The paired t test was used to evaluate the impact of AT on the echocardiographic parameters. The qualitative data are presented as numbers and percentages. The chi-square test was used to determine the potential association between groups for qualitative data. Pearson's correlation coefficient was used to assess the relationship between AHI and other

parameters. A p value less than 0.05 was considered to denote a significant difference.

Results

Study Populations

As shown by PSG, 18 patients had mild OSA (AHI 1–5), and 24 patients had moderate to severe OSA (AHI >5). The demographic features of the study groups and the systolic and diastolic blood pressure measurements are summarized in Table 1. Table 2 shows the distribution of various classes of adenoids and tonsillar size within the study groups.

Polysomnography

The PSG data were compared between the mild, moderate to severe, and control groups. Children with moderate to severe OSA had a higher oxygen desaturation index

Table 1 Demographic and clinical parameters of the study groups

	Patients ($n = 42$)	Control ($n = 45$)	p Value
Age (years)	5.21 ± 3	5.36 ± 3	0.81
Gender: male (%)	26 (61.9%)	24 (53.33)	0.42
Body weight (kg)	19.98 ± 8.9	20.15 ± 8.9	0.8
Height (cm)	109.7 ± 19.8	112.3 ± 18.4	0.53
BMI (kg/m^2)	15.85 ± 0.94	15.5 ± 1.44	0.19
SBP (mmHg)	89.2 ± 11	90.4 ± 8.8	0.56
DBP (mmHg)	64.5 ± 4.8	65.5 ± 5.4	0.34

BMI body mass index, *SBP* systolic blood pressure, *DBP* diastolic blood pressure

Table 2 Ear, nose, and throat (ENT) examination findings of the study groups

	Patients ($n = 42$) n (%)	Control ($n = 45$) n (%)
Adenoids		
+1	0 (0)	40 (88.8)
+2	7 (16.7)	5 (11.1)
+3	28 (66.7)	0 (0)
+4	7 (16.7)	0 (0)
Brodsky scale for tonsils		
+1	0 (0)	41 (91.11)
+2	15 (35.7)	4 (8.88)
+3	22 (25.4)	0 (0)
+4	5 (11.9)	0 (0)

($p < 0.001$) and a lower oxygen saturation ($p < 0.001$) than the mild group. Moreover, comparison of the mild OSA patients with the patients in the control group showed that the patients with mild OSA had a significantly higher oxygen desaturation index ($p < 0.001$) and a significantly lower oxygen saturation ($p < 0.001$) (Table 3).

Echocardiography

The data from the conventional echocardiography of the three different study groups are listed in Table 4, and the TDI findings for the various study groups are summarized in Table 5. The post hoc test showed that the patients with moderate to severe OSA had significantly greater RVDd, mPAP, PASP, PVR, and LVMi values than the patients in the mild OSA and control groups. Furthermore, the patients with mild OSA had significantly higher values than the children in the control group.

Calculation of PVR by echocardiography showed that the patients with moderate to severe OSA had higher PVR values than the patients with mild OSA ($p < 0.001$) and that the patients with mild OSA had significantly higher PVR values than those in the control group ($p < 0.001$). The patients and the control children did not differ significantly with regard LVIDd, LVIDs, LA diameter, FS%, or mitral inflow velocity. We found that the patients with moderate to severe OSA had a lower tricuspid E-wave velocity and E/A ratio than the patients with mild OSA ($p < 0.001$) and the control subjects ($p < 0.001$). However, the patients with mild OSA did not differ significantly from the control subjects in terms of tricuspid E-wave velocity ($p = 0.88$) or E/A ratio ($p = 0.61$). No significant differences were observed between the three groups in terms of tricuspid A-wave velocity.

Assessment of LV function by TDI echocardiography showed that the patients with moderate to severe OSA had significantly lower mitral annular Em-wave velocity ($p < 0.001$) and Em/Am ratio ($p < 0.001$) values, significantly increased sum of ICT and IRT values, significantly shortened ET, and consequently higher LVMPI values ($p < 0.001$) than the children in the control group. Similar findings were demonstrated when the patients with mild OSA were compared with the control subjects. Mitral annular Am and Sm velocities did not differ significantly between the three groups.

Furthermore, assessment of RV function by TDI echocardiography showed a reduction in tricuspid annular Em wave velocity and the Em/Am ratio, an increased sum of ICT and IRT, a shortened ET, and a higher RVMPI in the patients with moderate to severe OSA than in the patients with mild OSA and those with mild OSA than in the control subjects. Tricuspid annular Am-wave and Sm-wave velocities were similar in the three groups (Table 5).

Table 3 Polysomnography findings of the study patients and control subjects

	Patients with mild OSA (n = 18)	Patients with moderate-severe OSA (n = 24)	Controls (n = 45)	p Value
AHI	3.48 ± 1.0	11.74 ± 2.6	0.46 ± 0.1	P1 < 0.001[a]
				P2 < 0.001[a]
				P3 < 0.001[a]
Oxygen desaturation index	2.57 ± 1.0	11.7 ± 2.6	0.33 ± 0.13	P1 < 0.001[a]
				P2 = 0.006[a]
				P3 < 0.001[a]
Lowest oxygen saturation (%)	90.5 ± 1.46	80.4 ± 5.0	98.1 ± 0.8	P1 < 0.001[a]
				P2 < 0.001[a]
				P3 < 0.001[a]

OSA obstructive sleep apnea, *AHI* apnea hypopnea index, *P*1 mild vs moderate to severe cases, *P*2 mild cases vs. controls, *P*3 moderate to severe cases vs controls

[a] Significant

Table 4 Conventional echocardiographic parameters of control subjects and patients with obstructive sleep apnea (OSA) before adenotonsillectomy (AT)

LA (cm)	Patients with mild OSA (n = 18)	Patients with moderate-severe OSA (n = 24)	Controls (n = 45)	P3	P2	P1
LA (cm)	1.88 ± 0.15	1.99 ± 0.3	1.93 ± 0.22	0.74	0.41	0.32
RVDd (cm)	1.61 ± 0.07	1.81 ± 0.27	0.83 ± 0.16	0.005*	<0.001*	<0.001*
LVIDd (cm)	2.9 ± 0.34	3.08 ± 0.35	3.07 ± 0.39	0.15	0.14	0.96
LVIDs (cm)	1.87 ± 0.18	1.95 ± 0.19	1.9 ± 0.18	0.21	0.55	0.36
FS%	35.4 ± 0.5	36.5 ± 3.9	37.6 ± 5.3	0.46	0.14	0.35
mPAP (mmHg)	20.2 ± 1.66	32.5 ± 4.2	5.2 ± 1.89	<0.001*	<0.001*	<0.001*
PASP (mmHg) [#]	32.5 ± 3.4[#]	55.33 ± 7.5[#]	9.2 ± 1.0[#]	<0.001*	<0.001*	<0.001*
PVR (WU) [#]	2.62 ± 0.95[#]	4.28 ± 1.7[#]	0.58 ± 0.09[#]	0.002*	<0.001*	<0.001*
LVMi (gm/m$^{2.7}$)	74.12 ± 4.1	95.3 ± 13.3	50.2 ± 1.8	<0.001*	<0.001*	<0.001*
Mitral						
E (cm/s)	8.0 ± 0.25	8.11 ± 0.32	0.56	0.57	0.7	0.27
A (cm/s)	3.91 ± 0.11	4.0 ± 0.14	3.97 ± 0.15	0.48	0.97	0.41
E/A ratio	2.0 ± 0.04	2.02 ± 0.02	2.02 ± 0.04	0.93	0.63	0.53
Tricuspid						
E (cm/s)	6.17 ± 0.21	5.48 ± 0.33	6.27 ± 0.24	<0.001*	0.88	<0.001*
A (cm/s)	3.28 ± 0.1	3.39 ± 0.18	3.3 ± 0.13	0.06	0.17	0.13
E/A ratio	1.86 ± 0.07	1.62 ± 0.13	1.88 ± 0.09	<0.001*	0.61	<0.001*

LA left atrial diameter, *RVDd* right ventricular diastolic diameter, *LVIDd* left ventricular end diastolic diameter, *LVIDs* left ventricular end systolic diameter, *FS%* fractional shortening of the left ventricle, *mPAP* mean pulmonary artery pressure, *PASP* pulmonary artery systolic pressure, *PVR* pulmonary vascular resistance, *WU* wood's unit, *LVMi* indexed left ventricular mass, *E* early diastolic atrial filling, *A* atrial contraction

The study findings showed that OSA severity (represented by the AHI) was significantly correlated with the mitral annular Em/Am ratio ($r = -0.82$; $p < 0.001$), tricuspid annular Em/Am ratio ($r = -0.57$; $p < 0.001$), RVDd ($r = 0.49$; $p = 0.001$) (Fig. 1), mPAP ($r = 0.94$; $p < 0.001$), LVMi ($r = 0.83$; $p < 0.001$), RVMPI ($r = 0.98$; $p < 0.001$) (Fig. 2), and LVMPI ($r = 0.96$; $p < 0.001$) (Fig. 3). Additionally, the findings showed that RVMPI and LVMPI were correlated with mPAP ($r = 0.96$; $p < 0.001$ and $r = 0.91$; $p < 0.001$, respectively) (Fig. 3).

Effect of Treatment

The PSG parameters of the patients after AT were similar to those of the children in control group (Table 6). The significant reduction in AHI observed was associated with a significant reduction in RVDd, mPAP, PASP, and echocardiography-derived PVR and LVMi to levels comparable with those of the children in control group. Postoperatively, the tricuspid E-wave velocity and E/A ratio significantly increased ($p < 0.001$). The mitral annular Em,

Table 5 Tissue Doppler imaging (TDI) echocardiographic parameters in control subjects and patients with obstructive sleep apnea (OSA) before adenotonsillectomy (AT)

	Patients with mild OSA ($n = 18$)	Patients with moderate-severe OSA ($n = 24$)	Controls ($n = 45$)	P1	P2	P3
Mitral annulus						
Em (cm/s)	12.8 ± 0.6	10.44 ± 0.63	15.75 ± 1.04	$<0.001^a$	$<0.001^a$	$<0.001^a$
Am (cm/s)	6.17 ± 0.52	6.4 ± 0.71	6.1 ± 0.74	0.18	0.82	0.06
Em/Am ratio	2.08 ± 0.15	1.64 ± 0.26	2.59 ± 0.26	$<0.001^a$	$<0.001^a$	$<0.001^a$
Sm (cm/s)	7.8 ± 1.1	8.11 ± 1.22	7.98 ± 1.16	0.44	0.35	0.92
ICT + IRT (ms)	128.3 ± 3.7	144.0 ± 1.32	110 ± 0.64	$<0.001^a$	$<0.001^a$	$<0.001^a$
ET (ms)	221.4 ± 11.0	212.5 ± 2.97	328 ± 7.5	$<0.001^a$	$<0.001^a$	$<0.001^a$
LVMPI	0.4 ± 0.03	0.5 ± 0.03	0.33 ± 0.016	$<0.001^a$	$<0.001^a$	$<0.001^a$
Tricuspid annulus						
Em (cm/s)	9.7 ± 0.29	8.7 ± 0.5	15.7 ± 1.4	0.002^a	$<0.001^a$	$<0.001^a$
Am (cm/s)	6.6 ± 1.12	6.76 ± 0.82	6.76 ± 0.82	0.23	0.50	0.46
Em/Am ratio	1.5 ± 0.28	0.95 ± 0.09	2.11 ± 0.22	$<0.001^a$	$<0.001^a$	$<0.001^a$
Sm (cm/s)	12.0 ± 1.04	11.69 ± 0.9	11.69 ± 0.9	0.93	0.29	0.20
ICT + IRT (ms)	108.1 ± 2.6	127.04 ± 3.19	88.86 ± 5.28	$<0.001^a$	$<0.001^a$	$<0.001^a$
ET (ms)	291.1 ± 5.06	260.9 ± 9.3	309 ± 9.27	$<0.001^a$	$<0.001^a$	$<0.001^a$
RVMPI	0.31 ± 0.026	0.47 ± 0.03	0.28 ± 0.009	$<0.001^a$	$<0.001^a$	$<0.001^a$

EM early diastolic myocardial velocity, *Am* late diastolic myocardial velocity, *Sm* systolic myocardial velocity, *ICT* isovolumic contraction time, *IRT* isovolumic relaxation time, *ET* ejection time, *LVMPI* left ventricular myocardial performance index, *RVMPI* right ventricular myocardial performance index

[a] Significant

Em/Am ratio, tricuspid annular Em, and Em/Am ratio significantly increased after AT. In addition, RVMPI, LVMPI, and the sum of ICT and IRT of both the tricuspid and mitral annuli were found to be significantly decreased after AT, whereas the ET of both ventricles was significantly increased. Mitral and tricuspid annular Em, Em/Am ratio, ICT + IRT, ET, LVMPI, and RVMPI did not differ significantly from those of the control group (Tables 7, 8).

Discussion

In this study, we documented the occurrence of LV and RV dysfunction in children with OSA due to ATH. To our knowledge, this study is the first in the literature to measure the MPI of both ventricles using TDI for these patients before and after AT. We found that both the LV and RV TDI-derived MPIs were significantly higher in the patients with moderate to severe OSA and those with mild OSA than in the control children. The increase in MPI was due to the increased sum of the ICT and IRT as well as the shortened ET of both ventricles.

The MPI is a relatively new parameter that can be used to assess global systolic and diastolic myocardial function [52]. Its theory is based on the fact that abnormal systolic function often is accompanied by abnormal diastolic function. The systolic contraction and diastolic relaxation of myocardial fibers are dependent primarily on Ca^{2+} flow. Whereas Ca^{2+} inflow occurs during ICT, Ca^{2+} outflow occurs during IRT. Both ICT and ET are affected by systolic dysfunction, whereas IRT is affected by diastolic dysfunction. Consequently, the MPI is regarded as a valuable index for assessing global systolic and diastolic myocardial function at the same time, and findings have shown it to be correlated significantly with results observed during cardiac catheterization [53, 54].

The MPI usually is calculated using conventional PWD echocardiography. However, this method has some limitations. For example, measurement of the transmitral (or transtricuspid) flow and the LV (or RV) outflow tract flow separately and calculation of the MPI are relatively complex using this method [34, 48], and changes in heart rate make the results less reliable [32]. However, using TDI, the intervals between the end and onset of diastolic annular velocities are easier to measure, and it is more accurate for calculating the MPI within a single cardiac cycle away from heart rate fluctuation [34, 62].

Previous studies assessed RVMPI by conventional PWD echocardiography. Duman et al. [23] found that RVMPI measured by PWD was elevated in children with ATH, but these authors did not confirm the presence of OSA by PSG. Rather, they used the OSA severity score. Additionally,
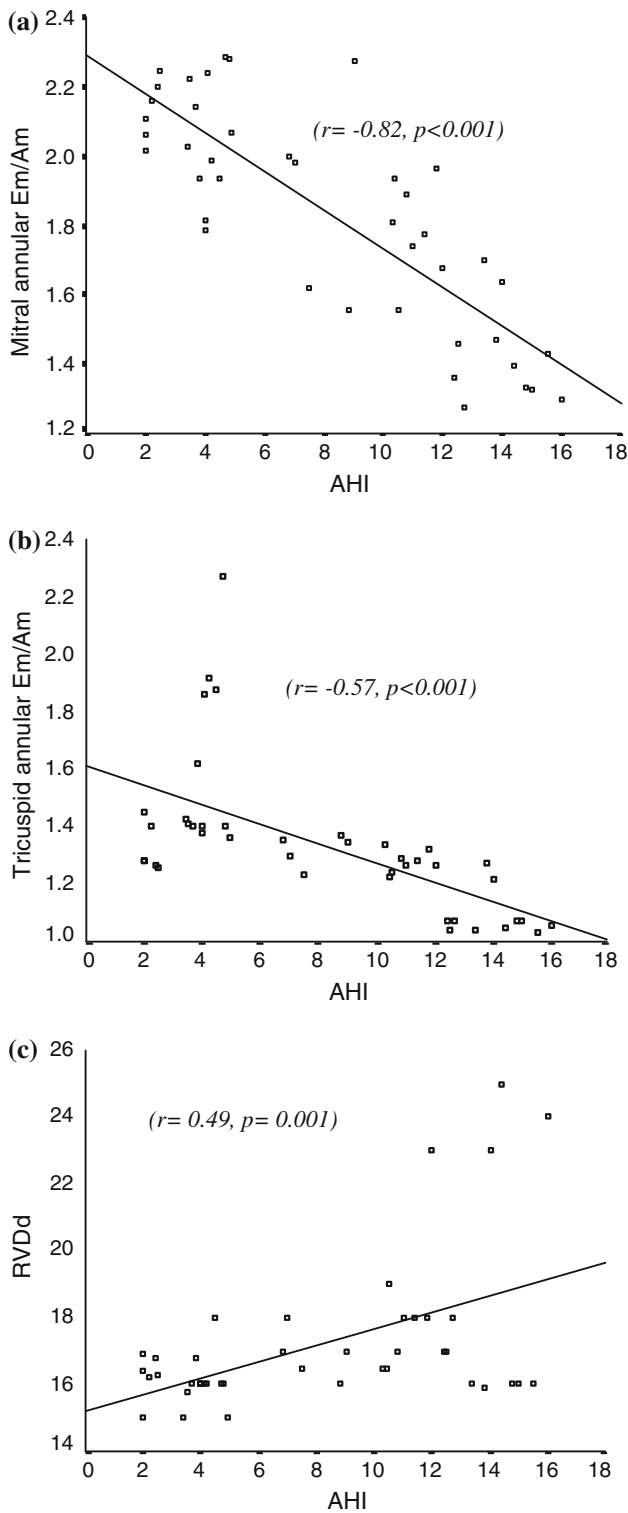
Fig. 1 **a** Scatter plot of the correlation between preoperative mitral annular Em/Am and the apnea-hypopnea index (AHI). **b** Scatter plot of the correlation between preoperative tricuspid annular Em/Am and AHI. **c** Scatter plot of the correlation between preoperative right ventricular diastolic diameter (RVDd) and AHI. Em, early myocardial diastolic velocity; Am, late myocardial diastolic velocity
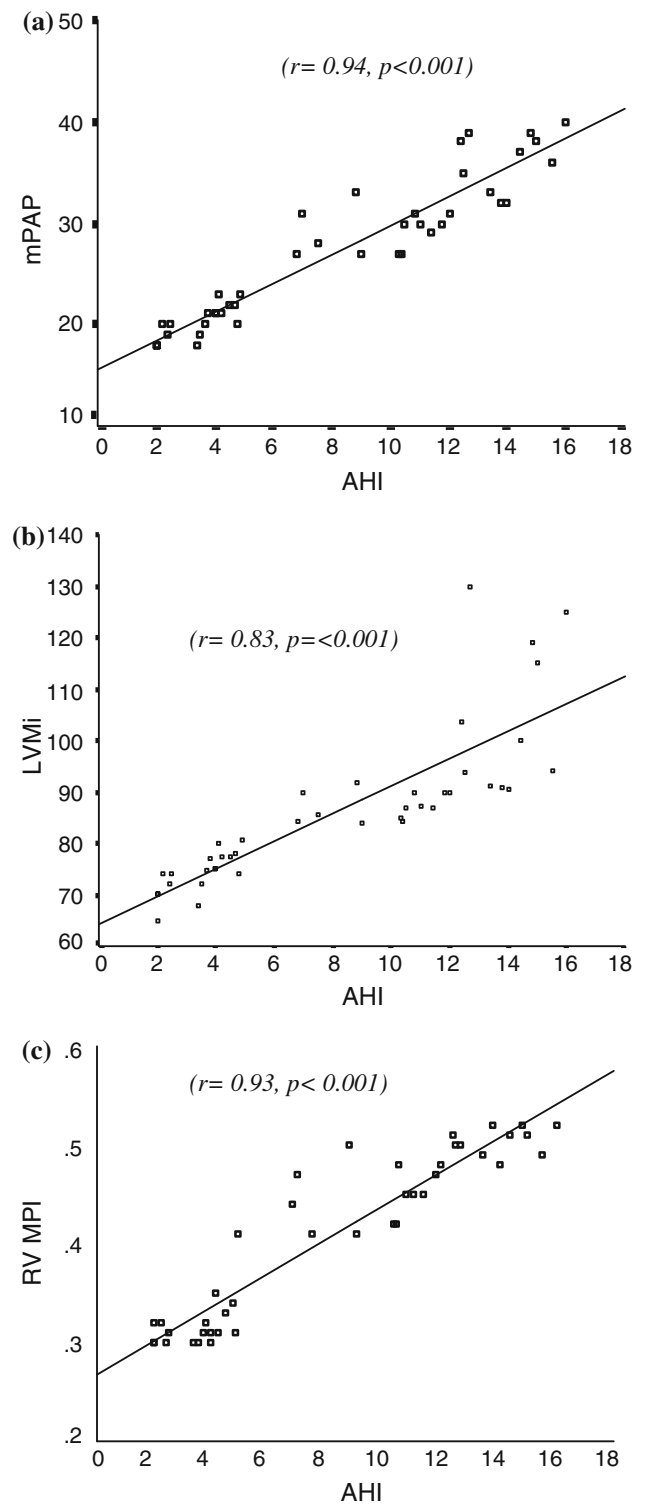
Fig. 2 **a** Scatter plot of the correlation between preoperative mean pulmonary artery pressure (mPAP) and the apnea-hypopnea index (AHI). **b** Scatter plot of the correlation between the preoperative indexed left ventricular mass (LVMi) and AHI. **c** Scatter plot of the correlation between the preoperative right ventricular myocardial performance index (RVMPI) and AHI
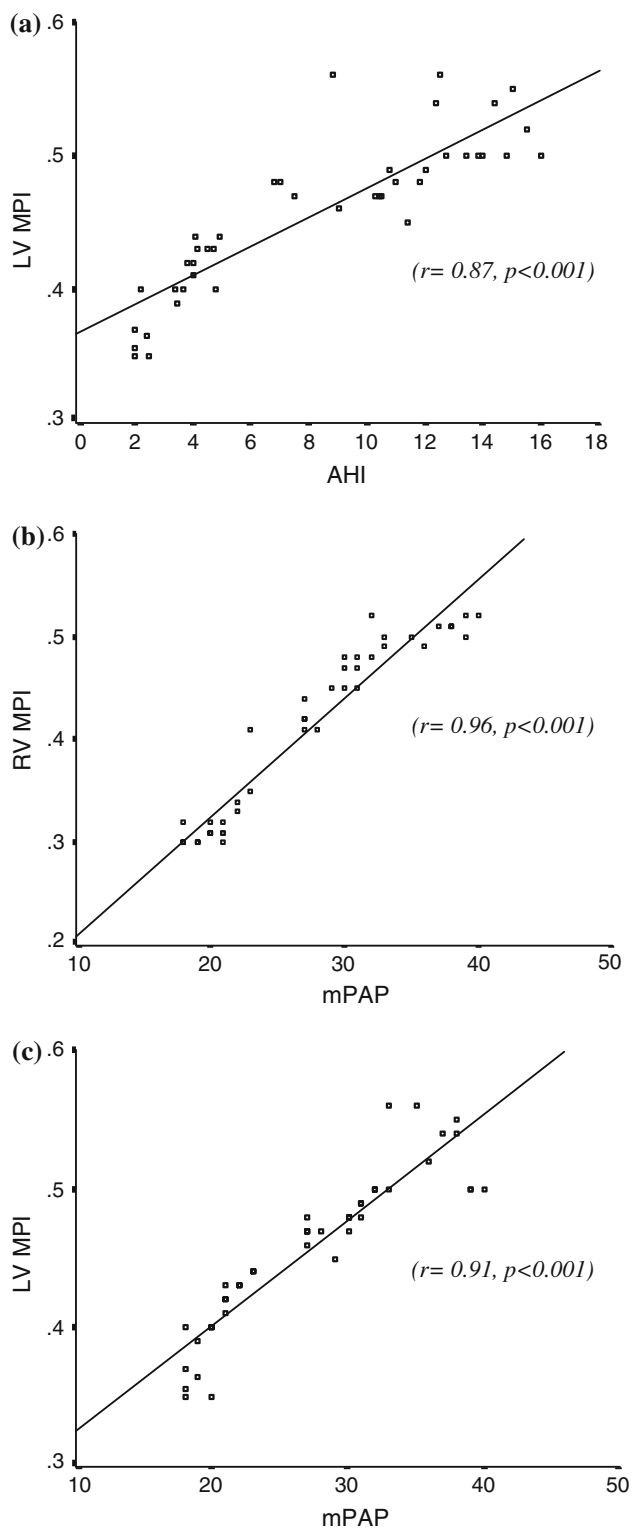
they did not investigate LVMPI. Using PWD, Cahn et al. [15] also observed a higher RVMPI in children with moderate to severe OSA (confirmed by PSG) than in those with mild OSA and those without OSA.

Many investigators have assessed RVMPI by TDI in adults with OSA [51, 55, 56]. Others have studied LV TDI-derived MPI [36–38, 45]. Bayram et al. [9, 10] assessed RVMPI and LVMPI by TDI, and their results were in accordance with our results. They also found that RVMPI and LVMPI improved after relief of OSA by nasal continuous positive airway pressure therapy.

Using TDI, we demonstrated LV diastolic dysfunction in the form of decreased mitral annular Em-wave velocity and Em/Am ratio. Similarly, RV diastolic dysfunction also was observed (i.e., decreased tricuspid annular Em-wave velocity and Em/Am ratio). These changes, in both ventricles, were more pronounced in patients with moderate to severe OSA, but patients with mild OSA had values significantly lower than those of the control children. Similar results were found in a study performed by Ugur et al. [57].

When we assessed LV and RV diastolic function by PWD echocardiography, we found that mitral E-wave and A-wave velocities and the E/A ratio of patients with any degree of OSA were similar to those of controls. A previous study demonstrated similar findings [57]. However, the patients with moderate to severe OSA had RV diastolic dysfunction (in the form of lowered tricuspid E-wave velocity and E/A ratio) compared with the patients with mild OSA and the control subjects.

Abd El-Moneim et al. [3] observed similar results in their study. However, in our study, we found no evidence of RV dysfunction in children with mild OSA. These children had a tricuspid valve E-wave velocity and E/A ratio similar to those of controls. Therefore, neither RV dysfunction in the patients with mild OSA nor LV dysfunction in the children with any degree of OSA could be detected by conventional PWD echocardiography.

Kumar and Jaggarao [39] found that continuous partial airway obstruction results in obstructive hypoventilation, which in turn leads to paradoxical respiratory efforts with diminished minute ventilation and ventilation perfusion abnormalities. Hypoxia and hypercapnia cause respiratory acidosis, which in turn leads to pulmonary arterial vasoconstriction, increased RV work, and cardiac hypertrophy.

We demonstrated that the PASP of the children with OSA was significantly greater than that of the control children. We calculated the mPAP using the pulmonary acceleration time and found it to be higher in the patients with OSA than in the control subjects. Several previous studies are in agreement with our results [28, 47].

Many years ago, pulmonary arterial hypertension with OSA, even cor pulmonale, was demonstrated [27, 50, 63].

Fig. 3 a Scatter plot of the correlation between the preoperative the left ventricular myocardial performance index (LVMPI) and the apnea-hypopnea index (AHI). b Scatter plot of the correlation between the preoperative right ventricular myocardial performance index (RVMPI) and the mean pulmonary artery pressure (mPAP). c Scatter plot of the correlation between preoperative LVMPI and mPAP

Table 6 Polysomnography parameters of patients before adenotonsillectomy (AT) and control subjects

	Patients with OSA before AT ($n = 42$)	Patients with OSA after AT ($n = 42$)	Controls ($n = 45$)	P1	P2
AHI	8.2 ± 4.6	0.5 ± 0.25	0.46 ± 0.1	<0.001[a]	0.32
Oxygen desaturation index	8.3 ± 6.9	0.36 ± 0.16	0.35 ± 0.17	<0.001[a]	0.14
Lowest oxygen saturation (%)	84.7 ± 6.37	97.85 ± 0.83	98.1 ± 0.8	<0.001[a]	0.83

OSA obstructive sleep apnea, *AHI* apnea-hypopnea index

[a] Significant

Table 7 Conventional echocardiographic parameters in patients with obstructive sleep apnea (OSA) before and after adenotonsillectomy (AT) and in control subjects

	Patients before AT ($n = 42$)	Patients after AT ($n = 42$)	Control ($n = 45$)	P1	P2
RVDd (cm)	17.25 ± 2.32	8.3 ± 1.6	8.3 ± 0.68	<0.001*	0.11
mPAP (mmHg)	27.23 ± 7.0	5.17 ± 0.6	5.22 ± 0.61	<0.001*	0.71
PASP (mmHg)[a]	46.92 ± 12.7[a]	9.16 ± 1.0[a]	9.2 ± 1.0[a]	<0.001*	0.58
PVR (mmHg)[a]	3.67 ± 1.67[a]	0.62 ± 0.07[a]	0.58 ± 0.09[a]	<0.001*	0.21
LVMi (gm/m^2)	86.2 ± 14.8	50 ± 2.5	50.244 1.89	<0.001*	0.75
TV E (cm/s)	5.77 ± 0.44	6.18 ± 0.22	6.18 ± 0.23	<0.001*	0.97
TV A (cm/s)	3.35 ± 0.17	3.34 ± 0.12	3.34 ± 0.13	0.66	0.74
TV E/A ratio	1.74 ± 0.16	1.85 ± 0.07	1.85 ± 0.07	<0.001*	0.84

P1 patients before AT vs. patients after AT, *P2* patients after AT vs. controls, *RVDd* right ventricular diastolic diameter, *mPAP* mean pulmonary artery pressure, *PASP* pulmonary artery systolic pressure, *PVR* pulmonary vascular resistance, *WU* wood's unit, *LVMi* indexed left ventricular mass, *TV* velocity time, *E* early diastolic atrial filling, *A* atrial contraction

* Significant

[a] Tricuspid regurgitation (TR) was measurable in 38 patients (90.4 %) and in 20 (44.4%) of control group

Table 8 Tissue Doppler imaging (TDI) echocardiographic parameters in patients with obstructive sleep apnea (OSA) before and after adenotonsillectomy (AT) and in control subjects

	Patients before AT ($n = 42$)	Patients after AT ($n = 42$)	Control ($n = 45$)	P1	P2
Mitral annulus					
Em (cm/s)	11.45 ± 1.32	15.56 ± 1.6	15.75 ± 1.4	<0.001[a]	0.57
Em/Am	1.83 ± 0.3	2.58 ± 0.25	2.59 ± 0.26	<0.001[a]	0.85
ICT + IRT (ms)	137.3 ± 8.29	108 ± 16.4	110 ± 6.4	<0.001[a]	0.41
ET (ms)	221.4 ± 11.0	329 ± 6.8	328 ± 7.5	<0.001[a]	0.44
LVMPI	0.45 ± 0.05	0.32 ± 0.05	0.33 ± 0.016	<0.001[a]	0.33
Tricuspid annulus					
Em (cm/s)	10.52 ± 1.94	13.85 ± 1.00	15.7 ± 1.4	<0.001[a]	0.23
Em/Am	1.3 ± 0.25	2.18 ± 0.32	2.11 ± 0.22	<0.001[a]	0.23
ICT + IRT (ms)	118.9 9.93	87.66 ± 4.4	88.86 ± 5.28	<0.001[a]	0.25
ET (ms)	273.8 ± 16.9	306.6 ± 7.38	309.4 ± 9.27	<0.001[a]	0.11
RVMPI	0.40 ± 0.084	0.28 ± 0.09	0.28 ± 0.009	<0.001[a]	0.69

Em early myocardial diastolic velocity, *Am* late myocardial diastolic velocity, *ICT* isovolumic contraction time, *IRT* isovolumic relaxation time, *ET* ejection time, *LVMPI* left ventricular myocardial performance index, *RVMPI* right ventricular myocardial performance index

[a] Significant

Furthermore, we found that PVR, as calculated by echocardiography, was elevated preoperatively. Many authors have previously studied the effectiveness of echocardiography as a noninvasive tool for measuring PVR and found that it correlated well with invasive measures of PVR during cardiac catheterization [2, 24, 39]. Moreover,

we found that RVDd was higher in the patients with OSA than in the control subjects before surgery and regressed after AT. These findings are in accordance with the results of previous studies [3, 23, 42, 60].

We measured LV mass indexed to height $^{2.7}$ (LVMi). We found that the patients with moderate to severe OSA had higher LVMi values than the patients with mild OSA and the control subjects, and that the patients with mild OSA still had significantly higher LVMi values than the control subjects. Increased LVMi in these patients has been described previously by Amin et al. [6]. Chan et al. [15] found elevated LVMi only in children with moderate to severe OSA but not in patients with mild OSA. However, the severity of OSA in their sample population was milder than in ours because they recruited patients from the community.

Left ventricular dysfunction can be explained by long-standing OSA and ineffective inspiratory efforts against occluded upper airway with a concomitant increase in the left ventricular afterload leading to the development of concentric compensatory left ventricular hypertrophy and increased oxygen demand by the LV myocardium [35]. The continuation of these ventricular stress episodes may induce ventricular remodeling and give rise to variable degrees of contractile dysfunction [16]. Furthermore, the excessive negative intrathoracic pressure during apnea may cause an alteration in LV relaxation properties [17]. Left ventricular filling also can be impaired because of leftward septal displacement caused by RV volume overload during OSA [58]. Additionally, hypoxemia can affect myocardial function by decreasing oxygen transport to the myocardium, augmenting sympathetic nervous system activity and encouraging the development of endothelial dysfunction [11].

When we correlated the echocardiographic parameters, we measured with the severity of OSA (AHI). We found that RV and LV TDI-derived MPI was significantly correlated with AHI. Similarly, RVDd, mPAP, LVMi, mitral annular Em/Am, and the tricuspid annular Em/Am ratio were significantly correlated with AHI. Duman et al. [23] correlated PWD-derived MPI with the OSA score but not AHI, whereas Chan et al. [15] observed a significant correlation between MPI (calculated by PWD) and AHI.

In the current study, mPAP but not PASP was included in the linear regression analysis to assess the correlation with AHI because tricuspid regurgitation was measurable in 38 of the patients (90.4%) and 20 of the control subjects (44.4%). Significant positive correlations between mPAP and both LV and RVMPI were found.

The relief of OSA after AT was documented using overnight PSG. All echocardiographic abnormalities observed in the patients with OSA regressed to values similar to those of the control group after AT. Many previous studies have demonstrated the reversibility of cardiorespiratory disturbances due to ATH after AT. Regression in RV diastolic dysfunction was observed in previous studies [15, 23, 28, 63]. Furthermore, a previous study by Amin et al. [6] found that LVMi regressed to normal values after AT in children with OSA.

Conclusion

This study found that OSA due to ATH in children adversely affects the global myocardial function of both ventricles. The myocardial performance index as measured by TDI is a very sensitive parameter that can be used to detect subclinical global myocardial dysfunction in these patients. Furthermore, myocardial dysfunction in these patients can be reversed by AT. Therefore, the early diagnosis and treatment of OSA in children is recommended to avoid cardiac dysfunction and other sequelae.

References

1. AASM (2007) The AASM manual for the scoring of sleep and associated events rules, terminology, and technical specification. AASM, Westchester, IL, pp 48–49
2. Abbas AE, Fortuin FD, Schiller NB, Appleton CP, Moreno CA, Lester SJ (2003) A simple method for noninvasive estimation of pulmonary vascular resistance. J Am Coll Cardiol 41:1021–1027
3. Abd El-Moneim ES, Badawy BS, Atya M (2009) The effect of adenoidectomy on right ventricular performance in children. Int J Pediatr Otorhinolaryngol 73:1584–1588
4. Ali NJ, Pitson DJ, Stradling JR (1993) Snoring, sleep disturbance, and behavior in 4- to 5-year-olds. Arch Dis Child 68:360–366
5. American Academy of Sleep Medicine (2005) International classification of sleep disorders: diagnostic and coding manual, 2nd edn. American Academy of Sleep Medicine, Westchester, IL, pp 56–59
6. Amin RS, Kimball TR, Kalra M, Bean JA, Jeffries JL, Willging JP, Cotton RT, Witt SA, Glascock BJ, Daniels SR (2002) Left ventricular hypertrophy and abnormal ventricular geometry in children and adolescents with obstructive sleep apnea. Am J Respir Crit Care Med 165:1395–1399
7. Amin RS, Carroll JL, Jeffries JL, Grone C, Bean JA, Chini B, Bokulic R, Daniels SR (2004) Twenty-four-hour ambulatory blood pressure in children with sleep-disordered breathing. Am J Respir Crit Care Med 169:950–956
8. Amin RS, Kimball TR, Kalra M, Jeffries JL, Carroll JL, Bean JA, Witt SA, Glascock BJ, Daniels SR (2005) Left ventricular function in children with sleep-disordered breathing. Am J Cardiol 95:801–804
9. Bayram NA, Ciftci B, Bayram H, Keles T, Durmaz T, Akcay M, Yeter E, Bozkurt E (2008) Effects of continuous positive airway pressure therapy on right ventricular function assessment by tissue Doppler imaging in patients with obstructive sleep apnea syndrome. Echocardiography 25:1071–1078
10. Bayram NA, Ciftci B, Durmaz T, Keles T, Yeter E, Akcay M, Bozkurt E (2009) Effects of continuous positive airway pressure therapy on left ventricular function assessed by tissue Doppler

imaging in patients with obstructive sleep apnoea syndrome. Eur J Echocardiogr 10:376–382

11. Brinker JA, Weiss JL, Lappé DL, Rabson JL, Summer WR, Permutt S, Weisfeldt ML (1980) Leftward septal displacement during right ventricular loading in man. Circulation 61:626–633

12. Brodsky L (1993) Tonsillitis, tonsillectomy, and adenoidectomy. In: Baily BJ (ed) Head and neck surgery-otolaryngology. JB Lippincott, Philadelphia, PA, pp 833–847

13. Brouillette RT, Thach BT (1979) A neuromuscular mechanism maintaining extrathoracic airway patency. J Appl Physiol 46:772–779

14. Brower CM, Gungor A (2000) Pediatric obstructive sleep apnea syndrome. Otolaryngol Clin North Am 33:49–75

15. Chan JY, Li AM, Au CT, Lo AF, Ng SK, Abdullah VJ, Ho C, Yu CM, Fok TF, Wing YK (2009) Cardiac remodelling and dysfunction in children with obstructive sleep apnoea: a community-based study. Thorax 64:233–239

16. Cloward TV, Walker JM, Farney RJ, Anderson JL (2003) Left ventricular hypertrophy is a common echocardiographic abnormality in severe obstructive sleep apnea and reverses with nasal continuous positive airway pressure. Chest 124:594–601

17. Cohn JN, Ferrari R, Sharpe N (2000) Cardiac remodeling: concepts and clinical implications: a consensus paper from an international forum on cardiac remodeling. International Forum on Cardiac Remodeling. Am Coll Cardiol 35:569–582

18. Corbo HM, Fuciarelli F, Foresi A, De Benedetto F (1989) Snoring in children: association with respiratory syndromes and passive smoking. BMJ 299:1491–1494 (published erratum appears in BMJ 1990;300:226)

19. Dabestani A, Mahan G, Gardin JM, Takenaka K, Burn C, Allfie A, Henry WL (1987) Evaluation of pulmonary artery pressure and resistance by pulsed Doppler echocardiography. Am J Cardiol 59:662–668

20. de Simone G, Daniels SR, Devereux RB, Meyer RA, Roman MJ, de Divitiis O, Alderman MH (1992) Left ventricular mass and body size in normotensive children and adults: assessment of allometric relations and impact of overweight. J Am Coll Cardiol 20:1251–1260

21. Devereux RB, Reichek N (1977) Echocardiographic determination of left ventricular mass in man: anatomic validation of the method. Circulation 55:613–618

22. Devereux RB, Alonso DR, Lutas EM, Gottlieb GJ, Campo E, Sachs I, Reichek N (1986) Echocardiographic assessment of left ventricular hypertrophy: comparison to necropsy findings. Am J Cardiol 57:450–458

23. Duman D, Naiboglu B, Esen HS, Toros SZ, Demirtunc R (2008) Impaired right ventricular function in adenotonsillar hypertrophy. Int J Cardiovasc Imaging 24:261–267

24. Ebeid MR, Ferrer PL, Robinson B, Weatherby N, Gebland H (1996) Doppler echocardiographic evaluation of pulmonary vascular resistance in children with congenital heart disease. J Am Soc Echocardiogr 9:822–831

25. Enright PL, Goodwin JL, Sherrill DL, Quan JR, Quan SF (2003) Blood pressure elevation associated with sleep-related breathing disorder in a community sample of white and Hispanic children. Tucson Children's Assessment of Sleep Apnea Study. Arch Pediatr Adolesc Med 157:901–904

26. Friedberg MK, Feinstein JA, Rosenthal DN (2006) A novel echo-Doppler method for estimation of pulmonary arterial pressures. J Am Soc Echocardiogr 19:559–562

27. Galal O, Galal I (1989) Cor pulmonale as a sequela of tonsillar hypertrophy (in German). Monatsschr Kinderheilkd 137:326–329

28. Görür K, Döven O, Unal M, Akkuş N, Ozcan C (2001) Preoperative and postoperative cardiac and clinical findings of patients with adenotonsillar hypertrophy. Int J Pediatr Otorhinolaryngol 59:41–46

29. Greenfeld M, Tauman R, DeRowe A, Sivan Y (2003) Obstructive sleep apnea syndrome due to adenotonsillar hypertrophy in infants. Int J Pediatr Otorhinolaryngol 67:1055–1060

30. Guilleminault C, Eldridge FL, Simmons FB, Dement WC (1976) Sleep apnea in eight children. Pediatrics 59:23–30

31. Guilleminault C, Korobkin L, Winkle R (1981) A review of 50 children with obstructive sleep apnea. Lung 159:275–287

32. Harada K, Tamura M, Toyono M, Yasuoka K (1995) Effect of heart rate on left ventricular diastolic filling patterns assessed by Doppler echocardiography in normal infants. Am J Card 76:634–636

33. Harada K, Tamura M, Toyono M, Oyama K, Takada G (2001) Assessment of global left ventricular function by tissue Doppler imaging. Am J Cardiol 88:927–932, A9

34. Harada K, Tamura M, Toyono M, Yasuoka K (2002) Comparison of the right ventricular Tei index by tissue Doppler imaging to that obtained by pulsed Doppler in children without heart disease. Am J Cardiol 90:566–569

35. Hetzel M, Kochs M, Marx N, Woehrle H, Mobarak I, Hombach V, Hetzel J (2003) Pulmonary hemodynamics in obstructive sleep apnea: frequency and causes of pulmonary hypertension. Lung 181:157–166

36. Kawanishi Y, Ito T, Okuda N, Emura N, Hayashi T, Futai R, Yoneda H, Kitaura Y (2009) Alteration of myocardial characteristics and function in patients with obstructive sleep apnea. Int J Cardiol 133:129–131

37. Kepez A, Niksarlioglu EY, Hazirolan T, Ranci O, Kabul HK, Demir AU, Kaya EB, Kocabas U, Aytemir K, Sahin A, Tokgozoglu L, Nazli N (2009) Early myocardial functional alterations in patients with obstructive sleep apnea syndrome. Echocardiography 26:388–396

38. Kim SH, Cho GY, Shin C, Lim HE, Kim YH, Song WH, Shim WJ, Ahn JC (2008) Impact of obstructive sleep apnea on left ventricular diastolic function. Am J Cardiol 101:1663–1668

39. Kumar EB, Jaggarao NS (1989) Adenotonsillar hypertrophy and cor pulmonale: clinical and echocardiographic correlation. Postgrad Med J 65:473–475

40. Lai WW, Geva T, Shirali GS, Frommelt PC, Humes RA, Brook MM, Pignatelli RH, Rychik J (2006) Guidelines and standards for performance of a pediatric echocardiogram: a report from the Task Force of the Pediatric Council of the American Society of Echocardiography. J Am Soc Echocardiogr 19:1413–1430

41. Messner AH (1999) Evaluation of obstructive sleep apnea by polysomnography prior to pediatric adenotonsillectomy. Arch Otolaryngol Head Neck Surg 125:353–356

42. Miman MC, Kirazli T, Ozyurek R (2000) Doppler echocardiography in adenotonsillar hypertrophy. Int J Pediatr Otorhinolaryngol 54:21–26

43. Mitchell RB (2007) Adenotonsillectomy for obstructive sleep apnea in children: outcome evaluated by pre- and postoperative polysomnography. Laryngoscope 117:1844–1854

44. Nishimura RA, Abel MD, Hatle LK, Tajik AJ (1989) Assessment of diastolic function of the heart: background and current application of doppler echocardiography. Part 2. Clinical studies. Mayo Clin Proc 2:181–204

45. Okuda N, Ito T, Emura N, Suwa M, Hayashi T, Yoneda H, Kitaura Y (2007) Depressed myocardial contractile reserve in patients with obstructive sleep apnea assessed by tissue Doppler imaging with dobutamine stress echocardiography. Chest 131:1082–1089

46. Owen GO, Cater RJ, Robinson A (1996) Snoring, apnea, and ENT syndromes in the pediatric community. Clin Otolaryngol 21:130–134

47. Phillips B (2005) Sleep-disordered breathing and cardiovascular disease. Sleep Med Rev 9:131–140

48. Rojo EC, Rodrigo JL, Pérez de Isla L, Almería C, Gonzalo N, Aubele A, Cinza R, Zamorano J, Macaya C (2006) Disagreement

between tissue Doppler imaging and conventional pulsed-wave Doppler in the measurement of myocardial performance index. Eur J Echocardiogr 7:356–364

49. Sahn DJ, DeMaria A, Kisslo J, Weyman A (1978) Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. Circulation 58:1072–1078

50. Sofer S, Weinhouse E, Tal A, Wanderman KL, Margulis G, Leiberman A, Gueron M (1988) Cor pulmonale due to adenoidal or tonsillar hypertrophy or both in children: noninvasive diagnosis and follow-up. Chest 93:119–122

51. Tavil Y, Kanbay A, Sen N, Ciftçi TU, Abaci A, Yalçin MR, Köktürk O, Cengel A (2007) Comparison of right ventricular functions by tissue Doppler imaging in patients with obstructive sleep apnea syndrome with or without hypertension. Int J Cardiovasc Imaging 23:469–477

52. Tei C, Ling LH, Hodge DO, Bailey KR, Oh JK, Rodeheffer RJ, Tajik AJ, Seward JB (1995) New index of combined systolic and diastolic myocardial performance: a simple and reproducible measurement of cardiac function: a study in normals and dilated cardiomyopathy. J Cardiol 26:357–366

53. Tei C, Dujardin KS, Hodge DO, Bailey KR, McGoon MD, Tajik AJ, Seward SB (1996) Doppler echocardiographic index for assessment of global right ventricular function. J Am Soc Echocardiogr 9:838–847

54. Tei C, Nishimura RA, Seward JB, Tajik AJ (1997) Noninvasive Doppler-derived myocardial performance index: correlation with simultaneous measurements of cardiac catheterization measurements. Am Soc Echocardiogr 10:169–178

55. Tugcu A, Guzel D, Yildirimturk O, Aytekin S (2009) Evaluation of right ventricular systolic and diastolic function in patients with newly diagnosed obstructive sleep apnea syndrome without hypertension. Cardiology 113:184–192

56. Tugcu A, Yildirimtürk O, Tayyareci Y, Demiroglu C, Aytekin S (2010) Evaluation of subclinical right ventricular dysfunction in obstructive sleep apnea patients using velocity vector imaging. Circ J 74:312–319

57. Ugur MB, Dogan SM, Sogut A, Uzun L, Cinar F, Altin R, Aydin M (2008) Effect of adenoidectomy and/or tonsillectomy on cardiac functions in children with obstructive sleep apnea. ORL J Otorhinolaryngol Relat Spec 70:202–208

58. Virolainen J, Ventilä M, Turto H, Kupari M (1995) Effect of negative intrathoracic pressure on left ventricular pressure dynamics and relaxation. J Appl Physiol 79:455–460

59. Waters KA, Cheng AT (2009) Adenotonsillectomy in the context of obstructive sleep apnoea. Paediatr Respir Rev 10:25–31

60. Weber SA, Montovani JC, Matsubara B, Fioretto JR (2007) Echocardiographic abnormalities in children with obstructive breathing disorders during sleep. J Pediatr (Rio J) 83:518–522

61. Wiatrak BJ, Wooly AL (1998) Pharyngitis and adenotonsillar disease. In: Fredrickson JM, Harker LA, Krause CJ, Richardson MA, Schuller DE, Cumings CW (eds) Otolaryngology, head and neck surgery. Mosby-Year Book Inc., Saint Louis, pp 188–215

62. Yasuoka K, Harada K, Toyono M, Tamura M, Yamamoto F (2004) Tei index determined by tissue Doppler imaging in patients with pulmonary regurgitation after repair of tetralogy of Fallot. Pediatr Cardiol 25:131–136

63. Yilmaz MD, Onrat E, Altuntaş A, Kaya D, Kahveci OK, Ozel O, Dereköy S, Celik A (2005) The effects of tonsillectomy and adenoidectomy on pulmonary arterial pressure in children. Am J Otolaryngol 26:18–21