Anatomical and Functional Assessment of Upper Airway Performance Using Innovative NasoOroSpirometer and Cone Beam Computed Tomographic Diagnostic Devices in Children with Adenoid Hypertrophy – Observational Study

Edyta Zomkowska[1], Sylwia Grzybowska-Detka[2], Magdalena Zakrzewska[3], Jerzy Romaszko[4], Robert Barański[5], Andrzej Zając[6], Hanna Zajączkiewicz[7], Szymon Nitkiewicz[7], and Andrzej Kukwa[7]

[1]Clinical University Hospital in Olsztyn
[2]CMKP
[3] Independent Public Centre for Tuberculosis and Lung Diseases Treatment
[4]University of Warmia and Mazury in Olsztyn School of Medicine
[5]AGH University of Science and Technology
[6]Military University of Technology
[7]University of Warmia and Mazury in Olsztyn

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Abstract

Introduction. Adenoid hypertrophy leading to upper airway blockage is the most common cause of sleep apnoea syndrome in children. Moreover, the following disturbances can occur: normal speech resonance impairment, middle ear ventilation difficulties, and the development of an abnormal oral breathing pattern. Abnormal craniofacial growth and occlusal abnormalities can be observed as well. Objectives.The aim of the study was to confirm the relationship between respiratory disorders with the impaired upper airway patency resulting from reduced nasopharyngeal space. Moreover, an attempt was made to validate a new medical device, a NasoOroSpirometer, for diagnosing respiratory disorders resulting from adenoid hypertrophy. Design and Setting The NasoOroSpirometer is made up of three anemometric sensors (two nasal and one additional oral sensor) and is used to measure the airflow through the upper airways (UA). A measurement of the flow of air simultaneously through both nasal orifices was carried out in 105 children aged 4-8 years. The values obtained included the number of inhalations per minute, the inspiratory time and the inhalation volume. Results and discussion. The study demonstrated that children with adenoid hypertrophy had a statistically significantly lower number of inhalations through the nose than children from the control group. The current results demonstrated no statistically significant difference between the volume and the number of inhalations in both a combined analysis and in one analysis conducted separately for each nasal passage. The demonstrated statistically significant difference is most probably due to the oral compensation for the inefficient nasal respiratory pattern. A NasoOroSpirometric examination can be a screening tool in the assessment of UA patency disorders and an indicator for the eligibility for instrumental or imaging examinations.

Key points:

- Description of application of innovative devices and methods in the diagnostic process of impairments arising in upper respiratory tract in children

- NasoOroSpirometry indicates presence of anatomic anomalies in UA based on functional examination

- CBCT confirms anatomic and functional impairments observed in nasal spirometry

- Resection of hypertrophied adenoid in children increases quality of life

- Both previously mentioned methods are easy to perform, completely safe, quick and non-invasive. Abstract

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Adenoid hypertrophy in children is the most common cause of impaired upper airway patency [1]. Different degrees of airway obstruction may lead to the development of an abnormal pattern of breathing through the mouth (oral respiratory pattern). Impaired ventilation and exchange of air through the nose can increase the risk of secretory otitis media or chronic rhinitis [2]. A consequence of the latter is the obstruction of posterior nares, and the impaired patency of the Eustachian tube pharyngeal orifice. In this way, a classical "vicious disease circle" is initiated. A change in the breathing pattern can cause numerous abnormal consequences [3] – it is a causative factor of adenoid hypertrophy, palatine tonsil hypertrophy, and hypertrophy of the entire pharyngeal lymphatic system [4]. Consequently, it can lead to the manifestation of sleep apnoea syndrome (SAS) in children. Sleep disturbances with nocturnal arousals and sleep shallowing as well as sleep fragmentation occur [5, 6]. This results in impaired body recovery during sleep and excessive daytime sleepiness. Untreated SAS can lead to serious consequences, such as growth disorders, the development of hypertension, cardiac arrhythmias and even cognitive function disorders, e.g. ADHD (attention-deficit hyperactivity disorder) [1, 7, 8]. Adenoid hypertrophy is a mechanical obstruction resulting in the occlusion of the airways, particularly during sleep, and is one of the risk factors for the syndrome concerned.[9]

An examination that enables an objective assessment of the UA is cone-beam computed tomography (CBCT). This technique, currently widely applied by dentists and maxillofacial surgeons, is characterised by low radiation exposure when imaging both osseous and soft tissue structures. CBCT enables an objective 3D visualisation of the UA, the accurate determination of the absolute size of the adenoid, and the performance of its measurements in relation to the total nasopharyngeal volume. The examination also enables the imaging of the nasal sinuses, the volume of the petrous pyramids, and an assessment of the middle ear and the mastoid cells. The latter in the presence of adenoid hypertrophy, are the cause of impaired Eustachian tube patency, which leads to the abnormal development of petrous pyramid air spaces. In the sagittal plane of CBCT examination, the nasopharyngeal space and the location of the soft palate in relation to the posterior pharyngeal wall and the cervical spine can be assessed by performing Müller's manoeuvre. This procedure, the reverse of a Valsalva manoeuvre, involves closing the nostrils with fingertips during inhalation, which raises the soft palate and separates the nasal part from the oral part of the throat. In cases of lymphatic hyperplasia, the airflow through the upper airways within individual parts of the throat is then obstructed. The examination reveals the collapse of the posterior pharyngeal wall, which is diagnostically important in terms of the cause of obstructive apnoea [10, 11]. CBCT enables the visualisation of the discussed region and the avoidance of complications, e.g. an atlantoaxial subluxation during adenoidectomy, otherwise known as Grisel's syndrome [12, 13]. CBCT examination is relevant in the diagnostic process, particularly at the stage of qualifying for either surgical treatment (adenoidectomy/adenotonsillectomy) or non-invasive treatment, e.g. intranasal steroid therapy. Due to the low radiation dose, the examination is also carried out when assessing the progress of the proposed treatment [14, 15].

Methodology

Study population

This cohort study was conducted during a period of 2 years at [blinded for review]. The study participants comprised 105 children aged 4-8 years. In the group of the examined subjects: in 80 children, adenoid hypertrophy was revealed, while 25 children constituted a potentially healthy (control) group. In 80 children with symptoms characteristic of adenoid hypertrophy, a CBCT examination was conducted in order to visualise the anatomical structures of the upper airways The CBCT examination results provided eligibility for an adenoidectomy surgery and allowed the children to be assigned to individual groups according to the classification proposed by M.P. Major [16].

I. children with the adenoid occupying up to 25% (1/4) of the nasopharyngeal volume,

II. patients with the adenoid occupying up to 50% (1/2) of the nasopharyngeal volume,

III. patients with the adenoid occupying up to 75% (3/4) of the nasopharyngeal volume.

All 105 study patients were examined using a NasoOroSpirometer.

NasoOroSpirometry

A diagram of the device is provided in Fig. 1.

Fig. 1. A diagram and an image of the device: 1 – a mask with separate parts for the nose and the mouth, 2 – sensor casings, 3 – thermal anemometric sensors of the airflow, 4 – power supply and signal cables, 5 – a set of filters to condition the analogue signal, 6 – a data acquisition card, 7 – a PC computer. The device houses three constant-temperature anemometers connected by cables to a system conditioning the signal being measured. The voltage obtained in the measurements is archived in the PC's memory by means of the data acquisition card. The measuring sensors are made of tungsten wire with a diameter of 7.5 µm. The measuring fibres are placed in separate measurement canals – for the nasal canals with a diameter of 11 µm and the wall thickness of 2 mm in the nasal sensors, and in the "oral" canal with a diameter of 24 mm and the wall thickness of 3 mm. In each sensor, the casing is 30 mm long. The diameter of the measurement canals was selected so as not to suppress the airflow in the respiratory passages. The thermal anemometer fibre inside the casing is heated to 200°C. The measuring elements were pre-calibrated using known values of the airflow through the measuring system [17]. Each sensor was selected in consideration of the upper airflow measurement range at the level of 1,000 cm3/sec. An adult individual takes approx. 16 breaths per minute, with one (inhalation and exhalation) lasting for approx. 2 seconds. The tidal volume of an adult is approx. 500 cm3, i.e. the volume of the air flowing in one second (inhalation/exhalation) is 250 cm3, i.e. the average volume of a normal quiet breath. The number of measurements per unit of time at an assumed time of inhalation/exhalation should enable the reliable reconstruction of the monitored flow [18]. The recorded measurements were analysed using dedicated Breath Analyzer software developed for this purpose. The first step of the analysis involved the automatic identification of the onset of every inhalation. Where the automatic identification was doubtful, it was possible to make manual corrections of the analysed part of the examination. What was important in the analysis was the detection of the onset of each inhalation. The areas between the inhalation and exhalation starting points were counted as consecutive breaths. The

program enables the recording and assessment of the number of breaths per minute and the average time and volume of the inhalation and exhalation [17].**Fig. 2.** A record of NasoOroSpirometric examination showing the flow values, determined by individual orifices in the Breath Analyzer program (own materials).

The start of recording was preceded by the recording of the child's personal data, signing the parents' consent for the examination, and the description of the patient's history and clinical examination. The examination was conducted in a sitting position with at least one parent present. During the examination, the respiratory process was recorded in real-time. The measurements were read using a dedicated NoseSpirometer program, and the examination was analysed using the Breath Analyzer program. The NasoOroSpirometric examination measured the flow of air simultaneously through both nasal orifices. The following values were obtained: the number of inhalations, the inspiratory time per minute, and the inhalation volume.

Statistical analysis

A statistical analysis was carried out using the Statistica software (data analysis software system), version 13.3. Due to the lack of normal distribution of the study group, the statistical analyses were conducted using nonparametric Kruskal-Wallis tests. The statistical significance was assumed at $p < 0.05$. STROBE reporting method has been used to summarize the results of this study.

Ethical statement The study was conducted based on the consent issued by the [blinded for review] Resolution No. 16/2017 of 25 April 2017.

Results

The study group of patients (105 subjects) aged 4-8 years was divided into four groups depending on the CBCT examination result.

Group I comprised 19 (18%) patients, group II - 21 (20%) patients, while group III - 40 (38%) patients. The control group IV comprised 25 (24%) patients.

Table 1 . Analysis of age in individual study groups. A statistical comparison between the study group and control group, and an analysis of the results for the number of inhalations in study groups (I, II, III) in relation to the control group (IV) The tests on study subjects divided into the study group (comprising three groups: I, II, and III) and the control group IV confirmed that the study was conducted on children for whom the age difference was not statistically significant. The LN and RN data helped demonstrate a statistically significant difference between the study group and the control group in terms of the number of inhalations per minute. For the analysed cases, the p-value did not exceed 0.004. Children with adenoid hypertrophy had a statistically significantly lower number of inhalations through the nose than children from the control group.

Table 2. An analysis of the average inspiratory time per minute in individual study groups, and an analysis of the average inhalation volume in the study groups.

Discussion

The methods of accurate determination of nasal resistance, described in the literature, can be divided into two groups: methods for measuring the passive flow (passive rhinomanometry) and methods based on the measurement of the airflow during active breathing (active rhinomanometry) [19, 20]. The measurement involves pumping a specified volume of air at a pre-determined speed while measuring the differential pressure. It can be assumed that the differential pressure value is proportional to the nasal resistance. Currently, passive rhinomanometry is rarely applied. It is, however, useful in cases where the patient's cooperation is not possible, e.g. in young children [21]. A number of studies performed rhinomanometric measurements in children and adults in reference to chronic nasal patency disorders and adenoid hypertrophy [22-24]. A study by Zicari et al. included 71 children aged 6-12 years with symptoms of upper airway obstruction, who were diagnosed with "chronic mouth breathing". This research project, using a rhinomanometric examination, found normal nasal airflow in 19 (26.8%) children, while indicating nasal obstruction in 52 (73.2%) children. A follow-up rhinomanometric examination, performed following intranasal xylometazoline administration, confirmed the presence of nasal obstruction in 29 (55.7%) patients [24]. Researchers emphasise that rhinomanometry performed in children with adenoid hypertrophy can contribute to the better qualification of children for surgery.

The method, however, has serious disadvantages of which one should be aware of when employing it [25]:

1. the patient must hold their breath during the measurement,

2. in certain cases, the flow of the air being forced in can cause unpleasant sensations and involuntary movements of the soft palate, which leads to the inclusion of the resulting resistance value into the measurement result,

3. during the measurements using alternating-direction flow, significant differences are found between the force-in phase and the suction phase,

4. due to the use of nozzles, during each measurement, the air stream can be forced in at a different angle, which contributes to low repeatability of the examination,

5. the result of measurement by the passive rhinomanometric method has a form of a single numerical value that provides no information on the nasal flow dynamics. Moreover, the insertion of the nozzle into the vestibule of the nose during the examination prevents the assessment of the resistance of this upper airway section and the so-called "nasal valve" located between the vestibule and the proper nasal cavity.

An alternative to the rhinomanometric examination is NasoOroSpirometric examination conducted by the authors. The examination focuses on an analysis of airflow and the calculation of inspiratory volumes while departing from the measurement of pressures (which is characteristic of rhinomanometry).The difference between both procedures also lies in the elimination of non-physiological behaviours of the examined patient during the rhinomanometric measurement.

The examination does not absorb the patient's attention, apart from the mask placement, which is not very inconvenient, and its effect on the respiratory process is negligible.

The results obtained in the current study show that in patients with adenoid hypertrophy, the number of inhalations per minute is lower than in healthy children (Table 1). However, a hypertrophied adenoid has no statistically significant effect on the inspiratory time or volume (Table 2). It was demonstrated that in the group of patients with significant adenoid hypertrophy (40 children in group III), the number of inhalations was lower than that in the group of 25 potentially healthy children (group IV). During the examination of the children, no measurement of the flow through the mouth was recorded. At the time the examination was recorded, the oral sensor was inactive (switched off). Young children tolerate the oral measurement poorly and are much less cooperative with the oral sensor during the examination. Moreover, a mask with three openings will most likely prove useful for adults, e.g. patients with suspected obstructive sleep apnoea, where it will serve as an examination complementary to polysomnography (under study). This simple difference in the number of nasal breaths in the study group as compared to the control group results, most probably, from the compensation of the nasal respiratory pattern with the oral pattern by children with adenoid hypertrophy. Apart from the elimination of the airway obstruction symptoms, adenoid removal results in an increase in the nasopharyngeal space. Furthermore, it contributes to the restoration of patency of the posterior nare region. By performing adenoidectomy, the proper respiratory pattern and volume can be restored, and thus the number of inhalations by the nasal pattern at rest is increased. [18]. Imaging confirmation of the results of a screening NasoOroSpirometric examination can be provided by CBCT, which enables the precise determination of anatomical obstructions impairing the airflow through the upper airway [15].

Conclusions

The examination using a NasoOroSpirometer is easy to perform, completely safe, quick and non-invasive, with the initial results being displayed while the examination is being recorded. It can serve as a screening tool in assessing UA patency disorders and be helpful when qualifying patients for instrumental or imaging examinations.

The results indicated that a statistically lower number of inhalations are a result of compensatory mouth breathing. The obtained values of inspiratory volumes, analysed using the Breath Analyzer program, can be compared with a cone-beam computed tomographic examination of the upper airways. Disclosure Authors have no conflicts of interest.

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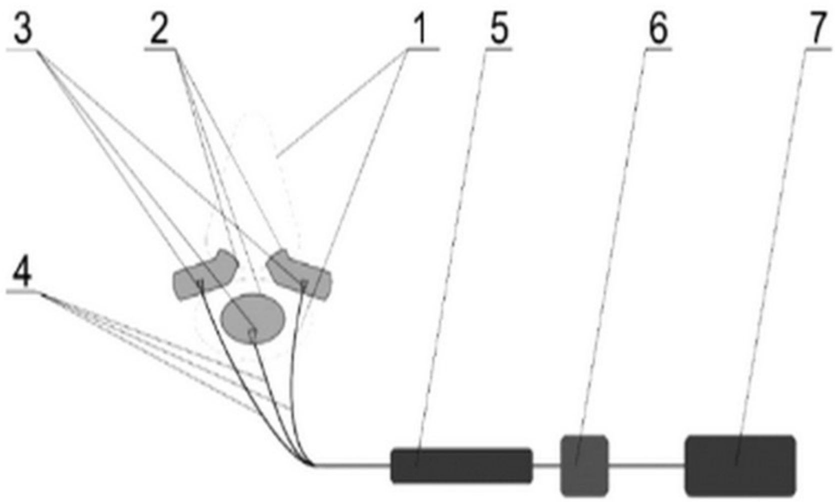
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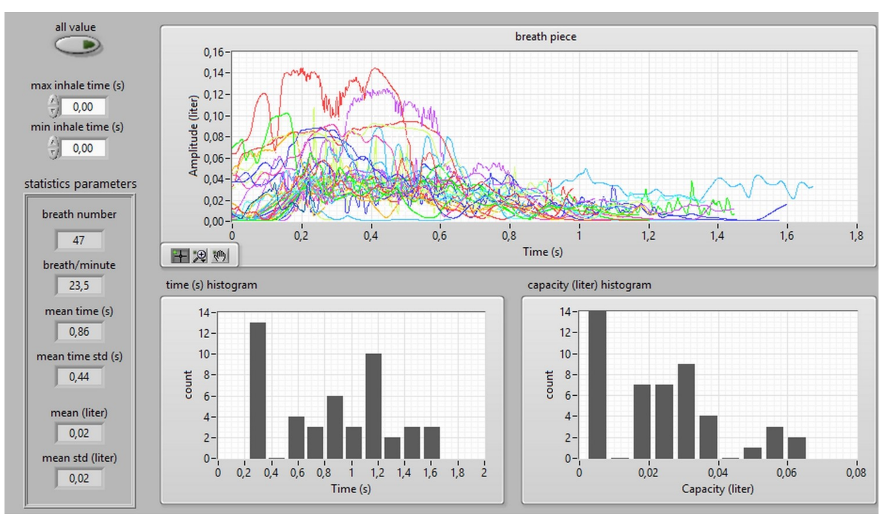
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