ADDENDUM

Addendum to 'Continuous assessment of nasal airflow resistance by adaptive modeling'

To cite this article: T Seppänen et al 2010 Physiol. Meas. 31 1547

View the article online for updates and enhancements.
Addendum to ‘Continuous assessment of nasal airflow resistance by adaptive modeling’

T Seppänen¹,², M Koskinen¹,⁴, T M Seppänen¹,² and O-P Alho²,³

¹ Department of Electrical and Information Engineering, University of Oulu, Oulu, Finland
² NoseMedical Ltd, Oulu, Finland
³ Department of Otorhinolaryngology, Institute of Clinical Medicine, University of Oulu, Oulu, Finland
E-mail: tapio.seppanen@ee.oulu.fi

Received 10 April 2010, accepted for publication 4 October 2010
Published 26 October 2010
Online at stacks.iop.org/PM/31/1547

Abstract
This addendum adds to the analysis of ‘Continuous assessment of nasal airflow resistance by adaptive modeling’ (Seppänen et al 2009 Physiol. Meas. 30 1197–209). The technical repeatability tests of the new nasal resistance measurement system presented here show that the resistance values remained very stable during two successive measurements indicating excellent repeatability.

Keywords: LMS, measurement, nasal resistance, respiration, repeatability

1. Introduction
In a recent study (Seppänen et al 2009) we presented a novel method to assess nasal airflow resistance in a way that provided a continuous resistance value and applied a minimally obtrusive measurement technique. Instead of calculating the resistance once for each breathing cycle conventionally, it was calculated for each signal sample at any sampling frequency. The continuous pressure recording was produced with a nasopharyngeal catheter inserted 8 cm deep along the floor of the other nasal cavity and the flow recording was produced with respiratory effort bands. A least-mean-square (LMS) extension for the resistance model of Broms et al (1982) was developed that dynamically adapts to the time-varying characteristics of the nasal functioning and produces the continuous resistance values. We presented experimental results that demonstrated the uniqueness and applicability of the new technique in assessing quickly changing resistance in a histamine/xylometatsolin challenges. With the new technique, the
There is one important further aspect that should be considered when a new diagnostic measurement system is presented. The technical repeatability of the measurement should be assessed. To address this issue, we present here an addendum to our previously published paper.

2. Methods and data

2.1. Calibration of respiration effort signals and calculation of continuous resistance values

The present measurement system (patent SE 530 004 C2 Sweden, patent FI 120132 B Finland) acquires the pressure signal by using a small catheter inserted transnasally into the nasopharynx, and the flow signal predicted from the respiratory effort signals after calibration with the regression method described in detail in our previous paper (Seppänen et al 2009).

2.2. Clinical data

All volunteers gave written informed consent and the study protocol was accepted by the institutional Ethics Committee of Oulu University Hospital. At enrolment, an ear, nose and throat specialist examined all the subjects. Background information was gathered using a questionnaire. The subject’s own comprehension of the nasal obstruction was graded from 1 (no symptoms) to 7 (worst possible) using a Visual Analogue Scale (VAS) score. The volunteers were not allowed to have a history of recurrent or chronic sinusitis and they had to be free of any acute respiratory symptoms during the prior two weeks to the measurements.

The new measurement system is prescribed earlier in detail (Seppänen et al 2009). Briefly, subjects sat in back upright position. Ultima SmartBelt™ respiratory effort bands (Braebon Medical Corp., Ogdensburg, NY, USA) were attached. The signals were recorded with polygraphic recorder (TrackIt, Lifelines Ltd, Hampshire, UK) with the sampling rate of 100 Hz. The pressure data were calibrated to physical units (Pascal) off-line with a manometer (Sper Scientific Ltd, Manometer model 840085, Scottsdale, AZ, USA). For calibrating the respiratory effort signals, 1 min of simultaneous control flow signal (c1) was recorded with a spirometer (Medikro M9404, Medikro Oy, Kuopio, Finland). Then, a sterile catheter (CH 06, Unomedical A/S, Denmark) (diameter 1 mm) was inserted 8 cm along the floor of the other nasal cavity into the nasopharynx, the tip of the catheter lying 1 cm anterior from the back wall of the nasopharynx. The catheter was connected to the differential pressure sensor (Braebon Ultima Dual Airflow Pressure Transducer) referenced to the atmospheric pressure. The protocol described in section 2.3 was then followed. The subjects were told to keep the same position and to breathe deep and peacefully and avoid speaking, sneezing and snuffling during the measurement. After all the protocol phases were finished, the pressure catheter was removed and the 1 min calibration (c2) recording was repeated. The calibration period c1 was used for training of the model while period c2 was used for assessing the model accuracy. $R^2$ statistics was calculated by estimating the flow during the period c2 and comparing the estimates with the real values from the spirometer. Then the roles of c1 and c2 were switched. The better model according to $R^2$ statistics was selected as final. After recording the signals were transferred from the recorder to the computer and stored in EDF format. All the signals were validated manually by using visualization software. All detected disturbances, originated for example from sneezing, snuffling and speaking, were deleted from the signals before analysis. Care was taken to maintain the correct synchrony between the signals.
Table 1. Clinical characteristics of the adult volunteers.

<table>
<thead>
<tr>
<th>Id</th>
<th>Sex</th>
<th>Age</th>
<th>Allergic rhinitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>30</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>48</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>22</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>49</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>23</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>24</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>22</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>57</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>22</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>50</td>
<td>No</td>
</tr>
</tbody>
</table>

2.3. Measurement of technical repeatability

To test the technical repeatability of the new measurement, ten adult volunteers were measured two times in succession. All subjects were non-smokers. The age of the volunteers varied from 22 to 57 years and all but one were male (table 1). Four subjects suffered from allergic rhinitis and six were healthy. To avoid changes in the environmental conditions (temperature and humidity), the subjects remained in the same room until both measurements were made. To minimize nasal mucosal variation, xylometazoline (1 mg ml\(^{-1}\)) was sprayed once in both nasal passages (Nasolin\textsuperscript{TM}, Orion Pharma, Helsinki, Finland) and cetirizine 10 mg was given per os (Zyrtec\textsuperscript{TM}, UCB Pharma, Helsinki, Finland) 30 min prior to the first measurement. The subjects first sat peacefully for 30 min prior to the first measurement. The respiratory effort bands as well as all other sensors were removed after the first measurement and reinstalled for the second measurement. Similarly, the nasal catheter was abolished after the first measurement and reinstalled on the same side for the second measurement. The baseline total resistance was recorded for 5 min twice for all these subjects. The pressure reference of 25 Pa was used for computing all resistance values. The time period between the two measurements varied approximately from 25 min to 1 h.

3. Results

The measurement value of the total nasal resistance remained stable during the two successive measurements as shown in table 2. The repeatability was quantified by calculating the average absolute change of resistance (3.7 Pa dm\(^{-3}\) s\(^{-1}\)) and dividing this by the overall average resistance (66 Pa dm\(^{-3}\) s\(^{-1}\)). This figure of merit was 5.6%, which indicates excellent repeatability. In addition, the Wilcoxon signed-rank test showed that there is no statistically significant change in the repeated resistance measurements (test statistic \(W = 22\), critical value for \(N = 10\) is 8 for \(p = 0.05\)).

4. Discussion

According to these further experiments, the new measurement system that enables continuous assessment of the nasal airflow resistance using a nasopharyngeal catheter and respiratory effort bands seems clinically applicable. The technical repeatability of the continuous resistance measurement was found to be clinically very good, as the differences between the two
successive measurements were small. No statistically significant differences were found with the Wilcoxon signed-rank test. Study subjects included both healthy and allergic persons. Previously, repeatability tests using similar protocols have shown that the differences between two successive measurements with conventional rhinomanometry are much larger (Sandham 1988, Cole 2000). The technical repeatability was assessed here and the nasal mucosal variation was stabilized using topical decongestant and systemic antihistamines similar to earlier studies dealing with the subject (Sandham 1988, Silkoff et al 1999, Harar et al 2001).

The biological repeatability is a much wider issue that may depend on several factors, like age, sex, posture, physical and mental effort, circadian rhythm, hormonal factors and autonomous nervous system, and was not assessed in this work.

The present measurement system requires the patient to remain in the same position during the measurement so that the respiratory effort bands are not displaced. The success of the calibration is reflected in the coefficient of determination between the spirometer signal and the flow estimate. The high coefficients of determination achieved here showed that the nasal airflow could be calculated accurately from the respiratory effort bands. Moreover, the coefficients of determination between two successive measurements were very similar despite the respiratory effort bands being removed and reinstalled. The time period between the two calibrations was relatively short here (5 min). Still, as the patient needs to remain in the same position during the measurement, long measurements, like overnight sleep studies, are not yet feasible with this system.

We conclude that the technical repeatability tests of the new nasal resistance measurement system presented here show that the resistance values remained very stable during two successive measurements indicating excellent repeatability.

Acknowledgment

We thank Mr Tapio Räihä for participating in the collection of the data.
Addendum

References


Cole P 2000 Acoustic rhinometry and rhinomanometry *Rhinology* **16** (Suppl.) 29–34


