Introduction & Background

- Multi-frequency bioelectrical impedance analysis (BIA) is a non-invasive method to assess body composition:
  - Total body water
  - Extra/Intracellular fluid
  - Fat and muscle mass

- Two forms of current move through the body:
  - Diffusion of charged ions through the body
  - Time rate of change of electric fields (displacement current)

Methods

- At low frequencies current can only pass through the extracellular matrix due to the capacitance of the cells. As we increase the frequency more and more current will flow through the intracellular matrix.

- Data is collected at various frequencies to construct a Cole-Cole plot.

Objectives

- The available devices are bulky, expensive, or cannot measure impedance continuously at multiple frequencies.
- The objective of this study is to design and develop an affordable, accurate, and portable device that can measure electrical tissue properties.

Methods

- Volume is determined by modeling each body segment as a truncated cone.

Proposed System Specifications

- Frequency Range: 1kHz – 2MHz
- Current Amplitude: 400µA
- Continuous Data Collection: 2kHz
- Wireless Transmission
- Battery Life: 8 Hours
- Electrodes: Gold cup electrodes

Future Work

- Design and build an affordable and portable multi-frequency bioimpedance device with the specifications listed above.
- Simultaneous measurements at multiple body segments, including leg and neck.
- Test the accuracy and efficiency of the device compared with existing models.
  - Potential Barriers
    - Generation of frequencies > 100kHz
    - Incorporating a large range of frequencies
    - Maintaining size and battery life

Contact

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Phone: 416-597-3030 ext 40123
Email: Azadeh.Yadollahi@uhn.ca
Introduction & Background

• Obstructive sleep apnea (OSA) is present in up to 10% of the population and increases the risk of cardiovascular morbidity and mortality\(^1\)
• Rostral fluid shift out of the legs and into the neck can increase severity of the sleep apnea (higher apnea hypopnea index, AHI)\(^2\)
• Increased time spent sitting increases the overnight change in leg fluid volume (LFV)\(^2\)
• Reducing the accumulation of fluid in the legs during the day can reduce the overnight rostral fluid shift and alleviate sleep apnea
• The purpose of my PhD is to investigate the use of electrical stimulation of the calf muscle at reducing leg fluid accumulation and alleviating sleep apnea severity

Hypotheses

1. Electrical stimulation of the calf muscle while seated reduces leg fluid accumulation compared to quiet sitting (control)
2. Compared to quiet sitting, reductions in leg fluid retention with electrical stimulation will reduce rostral fluid shift into the neck while lying down and alleviate sleep apnea

Methods

<table>
<thead>
<tr>
<th>Time course of the study:</th>
<th>Days 1 to 7</th>
<th>Day 8</th>
<th>Days 9 to 15</th>
<th>Day 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical activity &amp; diet</td>
<td></td>
<td>Study Day #1 &amp;</td>
<td></td>
<td>Study Day #2 &amp;</td>
</tr>
<tr>
<td>monitoring</td>
<td></td>
<td>Sleep monitoring</td>
<td></td>
<td>Sleep monitoring</td>
</tr>
</tbody>
</table>

Electrical Stimulation Parameters:

- Symmetric biphasic waveform at 35Hz with 300 μs pulse width
- Amplitude increased to max contraction (40 mA safety limit)
- Duty cycle: 2 seconds ON, 2 seconds OFF

Portable in-home sleep monitor

Details of the study day:

- Leg/neck/thoracic fluid:
  - Respiratory Rate:
  - UA-XSA:
  - ECG, HR and BP:
  - Pulse Oximetry:
  - Leg Circumferences:
  - Neck Circumference:
  - Bladder volume (void):

- Participant arrives:
  - Supine (30 min)
  - Sitting (4 hrs)
  - Supine (30 min)

Analysis of covariance (ANCOVA)

Primary outcomes

- Change in LFV while seated
- Change in LFV and neck fluid volume while supine
- Apnea hypopnea index

Secondary outcomes

- Urine volume
- Blood pressure
- Heart rate
- Cardiac output
- Heart Rate Variability

References:

2. Redolfi S. et al. AJRCCM 2009; 179: 241-6

Conclusions

- We have demonstrated that it is possible for electrical stimulation to reduce leg fluid accumulation in a single participant
- Data collection has begun and we aim to collect data from 20 men and 20 women over the next year

Acknowledgements

Funding:

- Collaborators:
  - Dr. T Douglas Bradley
  - Dr. Milos Popovic

Study Design & Subjects

Randomized double cross-over study

- Lie supine for 30 minutes
- Control Arm
  - Sham stimulation 4 hours
  - Lie supine for 30 minutes
- Intervention arm
  - Electrical stimulation 4 hours
  - Lie supine for 30 minutes
- Home sleep test
  - One week later cross-over to new arm

Sample size:

- 20 men and 20 women

Inclusion:

- Age: 40 - 70 years old
- BMI ≤ 30
- AHI ≥ 10
- Blood pressure <140/90

Exclusion:

- On treatment for sleep apnea
- Cardiovascular, circulatory or renal disease
- On medication affecting fluid retention

Data Analysis

Primary outcomes

- Change in LFV while seated
- Change in LFV and neck fluid volume while supine
- Apnea hypopnea index

Secondary outcomes

- Urine volume
- Blood pressure
- Heart rate
- Cardiac output
- Heart Rate Variability

Preliminary Results

Duty cycle: 2 sec ON, 30 sec OFF

- Leg fluid accumulation during 1 hour sitting with electrical stimulation, followed by a 10 minute washout, and then 1 hour of quiet sitting
- Duty cycle of 2 seconds ON and 30 seconds OFF was too infrequent to reduce leg fluid accumulation compared to quiet sitting
- Duty cycle of 2 seconds ON and 2 seconds OFF successfully reduced fluid accumulation in the legs

Acknowledgements

Funding:

- Collaborators:
  - Dr. T Douglas Bradley
  - Dr. Milos Popovic

References:

2. Redolfi S. et al. AJRCCM 2009; 179: 241-6
Developing Automatic Algorithms for non-Invasive Assessment of the Upper Airway Resistance

D. Zhi1,2, A. Hasanpour1,3, M. Popovic1,2; A. Yadollahi3
1 Toronto Rehabilitation Institute; 2 University of Toronto; 3 Ryerson University

Introduction & Background

• Increased upper airway resistance and the associated inspiratory flow limitation (FL) are important means to assess both the causes and the consequences of sleep disordered breathing.
• Based on Starling’s resistor model, Inspiratory flow limitation occurs when despite an increase in negative pharyngeal pressure, inspiratory flow remains constant or even decreases.
• Gold standard assessment requires invasive measurement of pharyngeal pressure.
• Some researchers have developed non-invasive techniques based on the contour of nasal airflow to detect flow-limited breaths during sleep with accuracies of 62-72% [1].
• Furthermore, it was shown that fluid accumulation in the neck during sleep could narrow the upper airway and increase its resistance during sleep.
• Neck fluid volume is measured by sensing electrodes placed on the right side of the neck.

Objectives

• Find relationship between fluid accumulation in the neck and the number of flow limited breaths during sleep.
• Develop automatic algorithms as the following, based on the contour of nasal airflow for non-invasive estimation of inspiratory flow limitation.

Methods

• Resample data to 40Hz
• Gaussian filter
• Flow-limited, Intermediate, Normal
• The following morphological features are necessary in determining the types of inspirations:
  o Normal: smooth bell shape
  o Flow-limited: an elevated plateau
  o Intermediate: otherwise
• Manual annotation is initially done to facilitate construction of the classifier. Results are compared with the following:
  o Change in Neck Circumference (NC)
  o Change in Upper Airway Cross-sectional Area (UA-XSA)
  o Change in Neck Fluid Volume (NFV)

Preliminary Results

• Data: 8 subjects with age (40±7.12), Body Mass Index (26±2.57), baseline NC (43±3.11), change in NC (1±0.5%), change in UA-XSA (-14±6%) and change in NFV (5±4%).
• Experiments show a 0.4s window size results in optimal filtering effect.
• The filtered signals look like the following:

Future Work

• To extract different features from flow contour such as the number and location of peaks and the plateau amplitude and to develop advanced classifiers based on Kalman filter and Markov process to detect inspiratory flow limitation.
• To investigate the relationship between increases in neck fluid volume during sleep and the number of flow limited breaths in a larger patient population.

Significance

• Improve assessment of the physiological cause and consequences of sleep disordered breathing
• Will be used to develop more sensitive measures for analysis of the upper airway narrowing during sleep.

Acknowledgements

Authors would like to thank TRI-Sleep team and Mr. D. Vena for their technical and scientific support.

A Convenient Wearable Device for Acoustic Scanning of the Upper Airway

P Hadi¹, B Westhead³, F Rudzicz¹,², A Yadollahi¹
¹ Toronto Rehabilitation Institute; ² University of Toronto, ³ iDAPT Somno

Introduction

• There is no simple and non-invasive technique to monitor variation in upper airway
• Upper airway structure can be monitored by MRI scanning or nasal endoscopy
• These methods are expensive and cannot be performed frequently

Method

The proposed device includes:
• A microphone: to record breathing and heart sounds
• An accelerometer: to extract position
• A wireless transmission module: to transmit collected data to a smart phone, tablet, or laptop
• Software interface: to communicate with the user and display the results
• Cloud storage: the collected data will be uploaded on a cloud storage to be processed and examined by a physician

Expected outcomes

• To assess abnormalities in the physiology and anatomy of the upper airway and pharynx
• To detect the amount of edema in the neck¹
• To assess cardiac function and heart rate variability by investigating heart sounds
• To diagnose and monitor breathing disorders during sleep
• To evaluate the effects of different treatments for sleep apnea and to adapt the treatments

Conclusion

The proposed device could improve monitoring of the upper airway and pharynx and enhance management of breathing disorders in a wide range of patients

Acknowledgments

Authors thank iDAPT Somno for their technical and financial support of this project.

References

Investigating the Effects of Neck Fluid Volume on the Snoring Sound Characteristics

S Saha1,2, Z Moussavi1, A Yadollahi2
1 University of Manitoba, 2 Toronto Rehabilitation Institute

Introduction

✓ Snoring is a prevalent disorder found in 20 – 40% of adult population.
✓ Recent studies have shown that increases in neck fluid volume (NFV) narrows the upper airway, and increases its resistance.
✓ NFV changes could increase turbulence of airflow passing through the airways, and consequently cause the vibration of soft tissues in the upper airway; thus, induce snoring.

Hypotheses

1) Fluid accumulation in the neck changes the snoring sounds features in time-frequency domain.
2) More NFV increases snoring sound complexity.

Methods

✓ Subjects: Ten non-obese men, 23 to 63 years old.
✓ Snoring sounds were recorded with a microphone placed over the neck.
✓ Segmentation: Snoring sound segments were extracted manually by listening to the sounds and observing them in the time-frequency domain.
✓ Feature Extraction: Snoring sounds features such as snoring duration and occurrence for various sleep stages and entire sleeping time were extracted.
✓ Statistical Analysis: Spearman’s rank correlation coefficient was used to see the relationship between NFV and snoring sounds features.

Results

Table 1: Characteristics of the Subjects (n = 10)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±STD</th>
<th>Variable</th>
<th>Mean±STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>48.6 ± 11.8</td>
<td>Total sleep time, min</td>
<td>127.1 ± 48.7</td>
</tr>
<tr>
<td>Height, cm</td>
<td>176.9 ± 5.9</td>
<td>N1 sleep, %</td>
<td>23.6 ± 8.3</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>82.3 ± 9.9</td>
<td>N2 sleep, %</td>
<td>54.5 ± 16.2</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.4 ± 3.0</td>
<td>N3 sleep, %</td>
<td>12.0 ± 14.6</td>
</tr>
<tr>
<td>NC, cm</td>
<td>43.3 ± 2.7</td>
<td>REM sleep, %</td>
<td>5.5 ± 6.3</td>
</tr>
<tr>
<td>UA-XSA, cm²</td>
<td>2.3 ± 0.6</td>
<td>Sleep Efficiency, %</td>
<td>65.5 ± 17.1</td>
</tr>
<tr>
<td>NFV, ml</td>
<td>253.3 ± 48.9</td>
<td>Total AHI</td>
<td>43.9 ± 24.0</td>
</tr>
<tr>
<td>SBP, mmHg</td>
<td>113.0 ± 11.0</td>
<td>Obstructive AHI</td>
<td>41.2 ± 24.8</td>
</tr>
<tr>
<td>DBP, mmHg</td>
<td>77.7 ± 11.3</td>
<td>Central AHI</td>
<td>2.6 ± 3.3</td>
</tr>
<tr>
<td>MAP, mmHg</td>
<td>89.1 ± 11.0</td>
<td>Average SaO₂</td>
<td>89.6 ± 5.2</td>
</tr>
</tbody>
</table>


Figure 1: Mean and standard deviation of snoring percentage in different sleep stages (n = 10)

Figure 2: Mean snoring Index (SI) which represents: number of snoring events per entire sleeping time in each sleep stage

Figure 3: Mean Snoring Time Index which represents: Snoring duration/Sleeping duration

Figure 4: Relationship between neck circumference and Non-REM2 Snoring Time Index

Discussion and Future Work

✓ Subjects had more percentage of snoring events in stage 2 of non-REM sleep (P < 0.01).
✓ Subjects with more increase in neck circumference after sleep had significantly more snoring duration index in non-REM 2 sleep stage.
✓ Future studies will include wider range of subjects to investigate the relationship between snoring features and changes in neck fluid volume and upper airway cross sectional area.
✓ More advanced snoring features such as energy, formant frequency, median bi-spectral frequencies will be extracted to investigate the hypotheses.

Acknowledgements

S. Saha was supported by the UMGF award. The authors would like to thank the TRI-Sleep team for their technical and scientific support.

References:
Investigating the Effects of Rostral Fluid Shift during Sleep on Inspiratory Flow Limitation in Men

D. Zhi1,2, E. Zola1,3, T.D. Bradley1,4, M.R. Popovic1,2, A. Yadollahi1,2

1University Health Network-Toronto Rehabilitation Institute; 2 Institute of Biomaterials and Biomedical Engineering, University of Toronto; 3 Ryerson University; 4 Department of Medicine, University of Toronto

Introduction

• During sleep, rostral fluid shift from the legs to the neck increases neck circumference (NC), narrows the upper airway cross-sectional area (UA-XSA), and worsens obstructive sleep apnea (OSA).
• However, the effects of fluid shift on UA narrowing during sleep have not been investigated before.
• Gold standard assessment of UA narrowing during sleep requires MRI or pharyngeal endoscopy which are cumbersome and cannot be performed routinely.
• Recently, non-invasive analysis of the nasal airflow contour has been used to assess the UA narrowing and inspiratory flow limitation during sleep.

Hypothesis

Patients with larger increases in neck fluid volume (NFV) during sleep will have more narrowing in the UA-XSA and higher percentage of inspiratory flow limited breaths.

Methods

• Inclusion criteria: non-obese men, 18-70 years.
• Exclusion criteria: history of cardiovascular, renal, or respiratory diseases, a previous diagnosis of OSA.
• Protocol: Voluntary sleep deprivation → Baseline Measurement → Supine daytime sleep study (PSG) → Measurements before and after sleep: Neck circumference (NC), Neck fluid volume (NFV), Upper airway cross-sectional area (UA-XSA) → Repeat Measurement → There was significant and negative correlation between baseline UA-XSA and percentage of flow limited inspirations.

• Statistical data analysis: correlation analysis was performed between percentage of inspiratory flow limited inspirations and baseline measurements.

Results

• Twenty men: age 39.2±12.3 years, BMI of 26.5±3.3 kg/m², and apnea/hypopnea index of 21.7±25.2 /h.
• After sleep, NC and NFV increased and UA-XSA decreased.
• 1150±452 inspiratory breaths during non-REM stage 2 of sleep were investigated for every individual.

• Flow Limitation during sleep.

Conclusion

• We found that men with narrower upper airway cross-sectional area and more increase in neck circumference due to rostral fluid shift had more percentage of flow-limited inspirations during sleep.
• These results could be used to develop novel algorithms to assess the effects of rostral fluid shift on the upper airway physiology and sleep apnea severity.

Future Work

• To develop automatic algorithms to detect flow limitation by extracting various features from each individual breath and their temporal variations.
• To validate the developed algorithms on clinical populations with fluid retaining conditions.

Acknowledgement

This study was supported by the CIHR Training Grant in Sleep and Biological Rhythms.

References:
Investigating the Effects of Fluid Accumulation in the Neck during Sleep on Snoring Sounds in Men

Shumit Saha1,2, Mahsa Taheri2, T Douglas Bradley2,3, Zahra Mossuavi1, Azadeh Yadollahi2,4
1 Dept. of Biomedical Engineering, University of Manitoba; 2 University Health Network-Toronto Rehabilitation Institute; 3 Dept. of Medicine, University of Toronto; 4 Institute of Biomaterial and Biomedical Engineering, University of Toronto

Introduction

- Rostral fluid shift during sleep can increase neck circumference (NC) and narrow the upper airway cross-sectional area (UA-XSA).
- Such narrowing in the UA-XSA may increase turbulence of airflow passing through the upper airway and induce snoring.

Objective

To investigate the variations in acoustic features of snoring with the changes in neck fluid volume (NFV), NC, and UA-XSA during sleep.

Methods

- Inclusion criteria: Non-obese men, 18-70 years.
- Exclusion criteria: History of cardiovascular, renal, or respiratory diseases, a previous diagnosis of sleep apnea.
- Protocol:
  - Baseline Measurement
  - Voluntary sleep deprivation
  - Supine day time sleep study (PSG)
  - Measurements before and after sleep: Neck circumference (NC), Neck fluid volume (NFV), Upper airway cross-sectional area (UA-XSA)
  - Continuous measurements during sleep: Snore sounds with a microphone.
  - Statistical data analysis: Correlation analysis was performed between snore features and baseline measurements.

Figure 1: Snore Sound Recording

Methods

- Time-domain snore sound features:
  - Snoring Percentage, %: number of snores in each sleep stage/ Total number of snores
  - Snoring Index: number of snore segments/total sleep time
  - Time Index, %: total snoring time/ total sleep time

- Frequency-domain snore sound features:
  - Average Power, dB; Relative Power, %; Spectral Centroid, Hz

Figure 2: Snore segments and its Spectrogram

Figure 3: Power Spectral Density of a snore segment

Results

Table 1: Characteristics of the Subjects (n = 20)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±STD</th>
<th>Sleep Structure</th>
<th>Mean±STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>43.8 ± 12.7</td>
<td>Sleep time, min</td>
<td>140.8 ± 43.5</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>25.2 ± 3.2</td>
<td>N1 sleep, %</td>
<td>19.0 ± 9.6</td>
</tr>
<tr>
<td>NC, cm</td>
<td>41.8 ± 3.1</td>
<td>N2 sleep, %</td>
<td>55.5 ± 16.2</td>
</tr>
<tr>
<td>UA-XSA, cm²</td>
<td>2.6 ± 0.6</td>
<td>N3 sleep, %</td>
<td>14.2 ± 15.2</td>
</tr>
<tr>
<td>NFV, ml</td>
<td>288.6 ± 60.6</td>
<td>REM sleep, %</td>
<td>8.8 ± 6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total AHI, /h</td>
<td>27.9 ± 24.8</td>
</tr>
</tbody>
</table>

- There were significantly more snores in the stage 2 non-REM sleep than other sleep stages (p<0.01).
- The maximum relative power of snoring was in the frequency range of [150 – 450] Hz (p<0.01).

Figure 4: Narrowing in the upper airway during sleep was correlated with significant increasing in the average power of snore sounds

Figure 5: Increasing in neck fluid volume during sleep decreased the spectral centroid frequency of the snore sounds

Discussion and Future Work

- Upper airway narrowing may increase snore sounds power by increasing air turbulence in the pharynx.
- Fluid accumulation in the neck increased low power components of snores; which may be due to increase in pharyngeal tissue thickness that can shift the resonance frequencies to the lower frequencies (Frequency = Velocity / 2×pharyngeal thickness).
- Future studies will investigate modeling of the upper airway and snore sound generation to validate theses possibilities.

Acknowledgement

S. Saha was supported by the UMGF award.

Introduction

• Fluid accumulated in the legs during the day is redistributed to the upper body while supine at night. The fluid displaced to the neck increases the neck circumference\(^1\), and upper airway resistance\(^2\) and its collapsibility\(^3\), predisposing the subject to sleep apnea, a common comorbidity of asthma.

• However, whether the fluid accumulated in the thorax contributes to worsening of asthma is unknown. This gap in the knowledge led us to investigate the effects of rostral fluid shifts on the pathophysiology of asthma.

Hypothesis

• Applying lower body positive pressure (LBPP) to the legs while supine will increase the shift of fluid out of the legs to the thorax, and cause lower (intrathoracic) airway narrowing in asthma.

Study Design & Subjects

Subjects

Healthy controls and asthma patients

Inclusion

• Age: 30-75 years
• BMI < 33kg/m\(^2\)

Exclusion

• History of hypertension, cardiovascular, renal, or neurological condition, and intake of medications for these
• Intake of medications that influence fluid retention

Methods

Data Analysis

Within each study arm:

Paired t-test to investigate the effect of time (form 0 min (pre-LBPP) to 30 min (post-LBPP)).

Between study arms:

Repeated measures ANOVA:

Factors

• Intervention (Control and active LBPP)
• Time (0 min (pre-LBPP) and 30 min (post-LBPP))

Subjects demographics and lung function

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Healthy</th>
<th>Asthma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, male/female</td>
<td>10/4</td>
<td>7/7</td>
</tr>
<tr>
<td>Age, years</td>
<td>50.7 (10.4)</td>
<td>57.9 (9.3)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>175.9 (9.8)</td>
<td>169.9 (12.2)</td>
</tr>
<tr>
<td>FEV(_1) %pred</td>
<td>104.4 (10.6)</td>
<td>69 (18.6)*</td>
</tr>
<tr>
<td>FEV(_1)/FVC</td>
<td>97.6 (9.4)</td>
<td>78.1 (16.2)*</td>
</tr>
<tr>
<td>R(_L) (cmH(_2)O/L/s)</td>
<td>3 (0.9)</td>
<td>6.9 (3.3)*</td>
</tr>
<tr>
<td>X(_S) (cmH(_2)O/L/s)</td>
<td>-0.9 (0.5)</td>
<td>-2.1(1.8)*</td>
</tr>
</tbody>
</table>

\( *p < 0.05 \)

Results

Conclusions

• Our results suggest that rostral fluid shift may contribute to the worsening of asthma by enhancing lower airway narrowing when supine, in particular in women and those with severe asthma.
• Further studies are required to investigate the effects of fluid shift during sleep.