A Bench Study of Polyvinylidene Fluoride (PVDF) Film Sensors and Nasal Cannula Pressure Sensors in Various Simulated Breathing Conditions to Identify Apnea and Hypopnea

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Introduction

Traditional methods of monitoring airflow during PSG include thermal sensors (thermistors or thermocouples) that can detect changes in air temperature and nasal cannula that can detect changes in air pressure. Polyvinylidine fluoride (PVDF) film sensors have been available as an option for monitoring airflow during polysomnography (PSG) as they are responsive to changes in both air temperature and pressure.[1]

The use of thermistors and thermocouples in PSG can be limited by the slow response rate and non-linear output of the devices, making them a reasonable tool for detecting apnea but are less precise in detecting hypopnea.[2,3] Conversely, monitoring nasal pressure via a nasal cannula has a rapid response time and can be more reliable in detecting hypopnea.[2,3] For this reason, PSG technicians often use both signals – nasal pressure via nasal cannula and air temperature via oral/nasal thermistor – to monitor and determine sleep disordered breathing events.

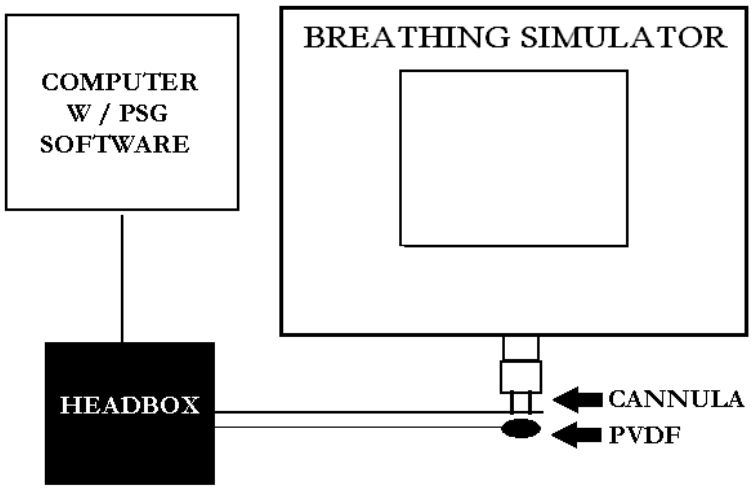
PVDF technology is used in a wide variety of applications including high-end stethoscopes, pacemakers, traffic light sensors, coin-operated vending machines, and LED illuminated tennis shoes.[1] PVDF is a plastic film that, when polarized with an electric charge, is sensitive to changes in temperature and pressure, and outputs a voltage when stimulated. PVDF sensors use only one channel, have a linear output, and can rapidly detect changes in both nasal and oral airflow, making PVDF a natural tool for PSG. PVDF sensors have already been approved by the American Association of Sleep Medicine (AASM) for apnea detection, but are not currently approved for hypopnea detection.

The purpose of this bench study was to compare the output of a traditional nasal pressure sensor to that of a PVDF sensor in simulated breathing conditions. These simulated conditions included normal, apnea, and hypopnea breathing patterns. Resulting nasal pressure and PVDF traces taken from the PSG software were compared for similarities in response time and event detection.

Methods and Materials

A breathing simulator (Series 1101, Hans Rudolph, Inc.) was programmed with flow patterns derived from nasal pressure signals taken from patients that had undergone PSG. These breathing patterns had previously been identified and scored, and were labeled as Normal, Apnea, and Hypopnea. Each pattern lasted approximately 10 minutes.

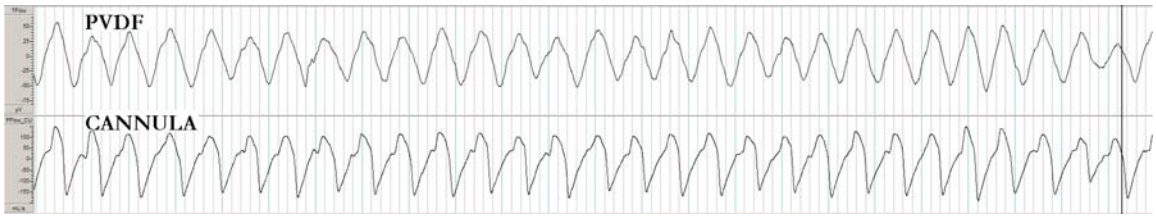
A nasal pressure monitoring cannula (SleepSense Ref 15805*, S.L.P. Inc.) was placed in the simulated patient airway of the breathing simulator. Additionally, a PVDF airflow sensor (Ref 10-10000-0510, Dymedix Diagnostics) was placed at the same outlet so that airflow to and from the simulator passed over both devices. Each device's connectors were plugged into the headbox of a PSG monitoring system (Remlogic 1.2, Embla Systems). With the breathing simulator running a simple breathing simulation, data output from each device was confirmed by observing traces on a PC operating the PSG monitoring software.



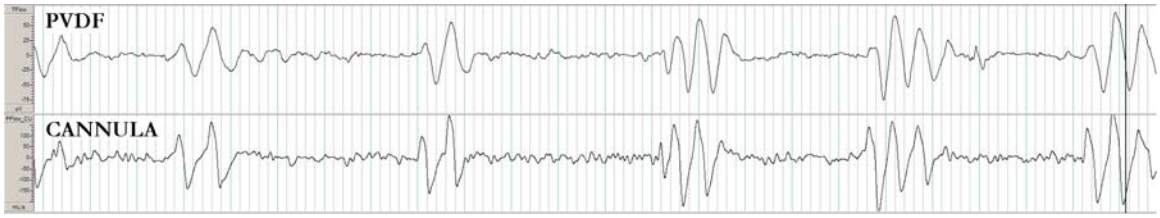
With the test setup and PSG software operational, the Normal breathing pattern programmed in the simulator was initiated. Data was automatically recorded by the PSG software for up to five minutes. Similarly, each of the Apnea and Hypopnea patterns was run and data recorded by the PSG software. On completion of the breathing simulations, data was extracted and screenshots of the nasal pressure and PVDF traces over a 2-minute period were taken.

Results

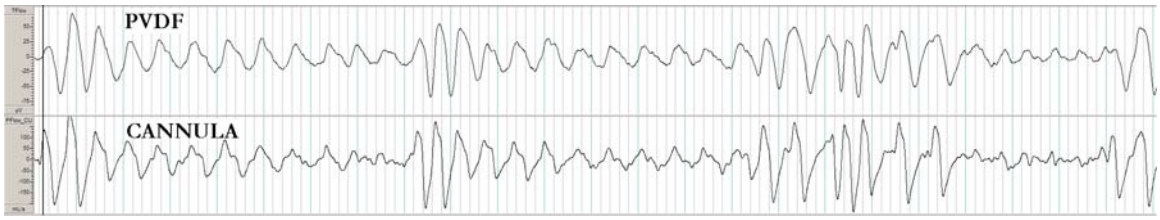
Normal Breathing Pattern



Apnea Breathing Pattern



Hypopnea Breathing Pattern



In all cases, visual inspection of the response characteristics of PVDF output compared to nasal pressure output showed very similar traces throughout the test period. Peaks and valleys seen in the traces, as well as breath-to-breath changes in peak flows, were near synchronous between the two methods in both time and amplitude. These tests were performed with temperatures in the test lung only slightly higher than ambient room temperature, making this comparison a relative apples-to-apples comparison of pressure signals despite the PVDF sensor's capability to also respond to changes in air temperature.

Results (Cont.)

Both methods clearly detected apneic breathing, with the output signals from each significantly reduced during the simulation's apneic events. Additionally, both methods clearly detected hypopneic breathing, with continual reductions in breath-to-breath peak flows and flow curves over time similarly appearing in both the PVDF and nasal pressure traces.

Discussion

Other studies have shown the ability of the PVDF sensor to adequately detect sleep disordered breathing when compared to traditional methods.[2,3,4] Like thermistors and thermocouples, where changes in temperature are the measurable output, PVDF sensors are currently approved by the AASM for use in detecting apneic events. Despite existing studies suggesting that PVDF sensors are adequate for detecting sleep disordered breathing events (both apneic AND hypopneic)[2,3,4,5], PVDF sensors are not an accepted method of hypopnea detection by the AASM. Results from this bench analysis, where comparison data between PVDF and nasal pressure traces relied more on pressure changes than temperature changes, and where nasal pressure output is considered the traditional method for detecting hypopnea, show that PVDF is adequately capable of detecting hypopneic events.

Potential lab benefits of the use of PVDF sensors in PSG include the reduction of the need for two channels to measure airflow (one for apnea and one for hypopnea) to one channel, which also eliminates the need for two separate sensors as the PVDF sensor is responsive to both pressure and temperature changes. This could be considered a cost benefit. In terms of output, PVDF has a linear output whereas nasal pressure output does not, meaning that PSG technicians do not need to consider or adjust parameters to account for the non-linearity of the nasal pressure signal output. Patient benefits may include the comfort of having only one oro-nasal sensor, eliminating the cannula and any restriction the cannula places on breathing, as well as eliminating cannula displacement issues.

Conclusion

Results show that the use of a PVDF sensor compares favorably to the use of a nasal pressure sensor via cannula in PSG studies, and that PVDF sensors are adequately capable of detecting apneic and hypopneic breathing patterns. PVDF sensors are a viable option for measuring patient airflow during PSG.

References

1. Eiken, Todd. "Going With the Flow." *Sleep Review*. Sleep Review: The Journal for Sleep Specialists, 4 Sept. 2005. Web. 07 Nov. 2014. <http://www.sleepreviewmag.com/2005/09/going-with-the-flow/>.
2. Berry, Richard B., Gary L. Koch, Steven Trautz, and Mary H. Wagner. “Comparison of Respiratory Event Detection by a Polyvinylidene Fluoride Film Airflow Sensor and a Pneumotachograph in Sleep Apnea Patients.” *CHEST* 128 (2005): 1331-1338. Print.
3. Kryger, Meir; Todd Eiken, and Li Qin. “The use of combined thermal/pressure polyvinylidene fluoride film airflow sensor in polysomnography.” *Sleep and Breathing* 17 (2013): 1267-1273. Print.
4. Goodrich, Susanne; Maroun Tawk, and William C. Orr. “The use of polyvinylidene fluoride (PVDF) film airflow sensors: an alternative to the nasal cannula for measuring respiratory events.” *Sleep Diagnosis and Therapy* 1.05 (2006): 30-31. Print.
5. Eiken, Todd. " Comparing Nasal Prong Pressure to Thermal Airflow Sensors." *Sleep Review*. Sleep Review: The Journal for Sleep Specialists, 3 July 2002. Web. 07 Nov. 2014. <http://www.sleepreviewmag.com/2002/07/comparing-nasal-prong-pressure-to-thermal-airflow-sensors/>.