# Unobtrusive, Through-clothing ECG and Bioimpedance Monitoring in Sleep Apnea Patients

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**Aim:** This study aims to evaluate the heart rate (HR) and respiration rate (RR) estimation performance of capacitively-coupled ECG (ccECG) and capacitively-coupled bioimpedance (ccBIOZ) signals from sleep apnea patients. This, by using polysomnography (PSG) signals (ECG and thoracic belt) as ground-truth. Such ccECG and ccBIOZ acquisition can be an important enabling technology for long-term monitoring of sleep apnea and cardiac patients in unrestricted environments.

**Methods:** Simultaneous PSG, ccECG and ccBIOZ signals were collected from 28 patients with suspected sleep apnea. ccECG and ccBIOZ signals were obtained from sensors in the mattress, without direct galvanic contact with the patients. PSG-ECG and ccECG signals were filtered in the [0.67-40]Hz band. PSG-respiration and ccBIOZ signals were low-pass filtered at 1Hz. ccECG HR evaluation was done for the complete dataset both with and without quality-based signal processing. ccBIOZ RR was evaluated for the first 11 patients due to data loss in the remaining cases. Performance metrics used were: Beat detection sensitivity and positive predictive value (PPV), R-R interval mean absolute error (MAE), tachogram correlation, window-based HR MAE and RR MAE.

**Results and Conclusions:** Results are shown in Table 1. Time domain ccBIOZ signals show a characteristic behavior in sleep apnea episodes that may be useful for automatic epoch identification. ccECG results without quality-based processing show that the ccECG presents parts of lower quality that can be caused by movement, positioning and the effect of PSG bands/harness overlapping with the electrodes. Results with quality-based processing show that ccECG signals can provide accurate beat detection and R-R intervals, when using an automatically selected data subset. RR values from ccBIOZ show promising results. Further research on the use of features from these signals for the detection and follow-up of sleep apnea and cardiac conditions will be part of future work, including the use of an extended dataset.

Table 1 Overall averaged performance metrics of ccECG and ccBIOZ-based respiration rate compared against PSG reference signals. Results correspond to an evaluation done in 60-second non-overlapping windows.

| Dataset | No. of Patients / Hours of recording | Sensitivity (%) | PPV (%) | R-R interval MAE (ms) | Tachogram correlation (%) | Window HR MAE (bpm) | Window RR MAE frequency-based (bpm) | Window RR MAE time-based (bpm) | Percentage of used data (%) |
|---|---|---|---|---|---|---|---|---|---|
| ccECG without quality-based processing | 28 patients / 295.2 h | 64.89 | 63.81 | 319.22 | 87.12 | 19.80 | -- | -- | 100 |
| ccECG with quality-based processing | 28 patients / 295.2 h | 98.45 | 98.01 | 17.09 | 99.59 | 1.55 | -- | -- | [19.3 – 73.2] range |
| ccBIOZ | 11 patients / 116.1 h | -- | -- | -- | -- | -- | 3.48 | 6.37 | 100 |