Approximate Entropy of Respiratory Movements in Human Newborns during Different Sleep States

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ABSTRACT

Previous studies have reported that the respiratory cycle of healthy newborns is more irregular during active sleep. This study aimed to apply non-linear analysis to examine the irregularity of respiratory movement in newborns at different sleep states. The respiratory movement signals from an abdominal band during quiet and active sleep were analyzed using approximate entropy (ApEn). The breathing interval of active sleep was significantly shorter than that of quiet sleep [1.30 (0.17) s vs. 1.58 (0.11) s; ($P < 0.03$)]. The ApEn of respiratory movements during active sleep were significantly larger than that during quiet sleep [0.785 (0.135) s vs. 0.678 (0.083) s; ($P < 0.05$)]. We found that the ApEn of respiratory movement in healthy newborns could detect irregularities in respiration during sleep.

Key words active sleep; approximate entropy; newborn; quiet sleep; respiration

The respiratory pattern of healthy newborns was reportedly more irregular during active sleep than during quiet sleep.[1] Moreover, sleep apneas in neonates frequently occur during active sleep.[2] The analysis of breathing patterns in neonatal sleep states have been based on respiratory rates and cycles.[3] Recently, a new non-linear analysis has been used to quantify biological signals, such as human respiration and electroencephalogram (EEG).[4, 5] In this study, we analyzed the respiratory pattern according to sleep states using approximate entropy[6] to investigate the respiratory irregularity in healthy newborns.

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Received 2015 November 25
Accepted 2015 December 17
Abbreviations: ApEn, approximate entropy; EEG, electroencephalogram; REM, rapid eye movement; SIDS, sudden infant death syndrome

SUBJECTS AND METHODS

We investigated eight healthy newborns within seven days after birth [gestational age 39.6 (standard deviation: 1.7) weeks, range: 37.0–41.9]. EEG signals were recorded (NicoletOne, IMI, Tokyo, Japan) from scalp surface electrodes (F3, F4, C3, C4, O1 and O2 by the International 10–20 System). We categorized the state of sleep-wake stage on the EEG records at 30-s intervals using the criteria defined by the American Association of Sleep Medicine.[7] We measured the respiratory movements of newborns during active and quiet sleep using an abdominal band (Quantum respiratory effort sensor; Pro-Tech services, Murrysville, PA). We selected three different 60-s artifact-free epochs of respiratory movements from each quiet or active sleep in newborns. The protocol was approved by the local ethics committee in Tottori University (# 2108). Written informed consent was obtained from the mother of each newborn.

The signals from respiratory movements were digitized with A/D converter (PowerLab, ADInstruments, Tokyo, Japan) at sampling rate of 10 Hz (0.1 s). The average approximate entropy (ApEn) of three epochs of respiratory movement from each sleep stage was estimated for the eight newborns.

We computed the ApEn of time series from respiratory movement during each sleep stage. In mathematical terms, ApEn was derived from the previously described correlation integral $C_{m,i}(r)$.[4–6] As described by Pincus,[6] the ApEn was computed as

$$\mathrm{ApEn}\ (N, m, r) = \Phi_m(r) - \Phi_{m+1}(r)$$

$$\Phi_m\ (r) = (N-(m-1))^{-1} \sum_{i=1}^{N-(m-1)} \log C_{m,i}(r)$$

$$\mathrm{ApEn}\ (N, m, r) = (N-(m-1))^{-1} \sum_{i=1}^{N-(m-1)} \log C_{m,i}(r) - (N-m)^{-1} \sum_{i=1}^{N-m} \log C_{m+1,i}(r)$$

where m represented the vector length, r represented the “filter factor”, and N represented the number of data points. The value of N for the ApEn computation is typically between 75 and 5000.[6] ApEn measures the logarithmic likelihood that close sets of patterns for *m*-observations remain close in the next incremental comparisons.[6] It characterizes how different segments of signals with similar recent histories remain similar in the future. As ApEn decreases, the complexity of the signal decreases and determinism is high.

In this study, the N was 600 (60 s); the set r was at 0.2 times the SD of the original data series; and $m = 2$ was used.[6] In order to facilitate interpretation of ApEn values of EEG signals, the ApEn of a time series of a sine wave was estimated to be 0.0001 (N = 600), as an example of a regular (linear) signal. The ApEn of a time series of uniformly distributed random numbers was estimated to be 1.538 (N = 600). We used the MatLab software (MathWorks, Natick, MA) to compute for the ApEn values.[4, 5]

Statistical analyses

The values of ApEn were presented as mean (SD). We used Wilcoxon matched pairs signed-rank test to compare ApEn values and assess for any difference between quiet and active sleep stages (Stat Flex; ViewFlex, Tokyo, Japan). Differences were considered to be statistically significant at $P < 0.05$.

RESULTS

Figure 1 shows an example of respiratory movements in a newborn at a sampling rate of 10 Hz. In the eight newborns, the breathing interval of active sleep was significantly shorter than that of quiet sleep [1.30 (0.17) s vs. 1.58 (0.11) s; ($P < 0.03$)]. The ApEn of respiratory movement was significantly higher during active sleep than during quiet sleep [0.785 (0.135) vs. 0.678 (0.083); ($P < 0.05$)] (Fig. 2).

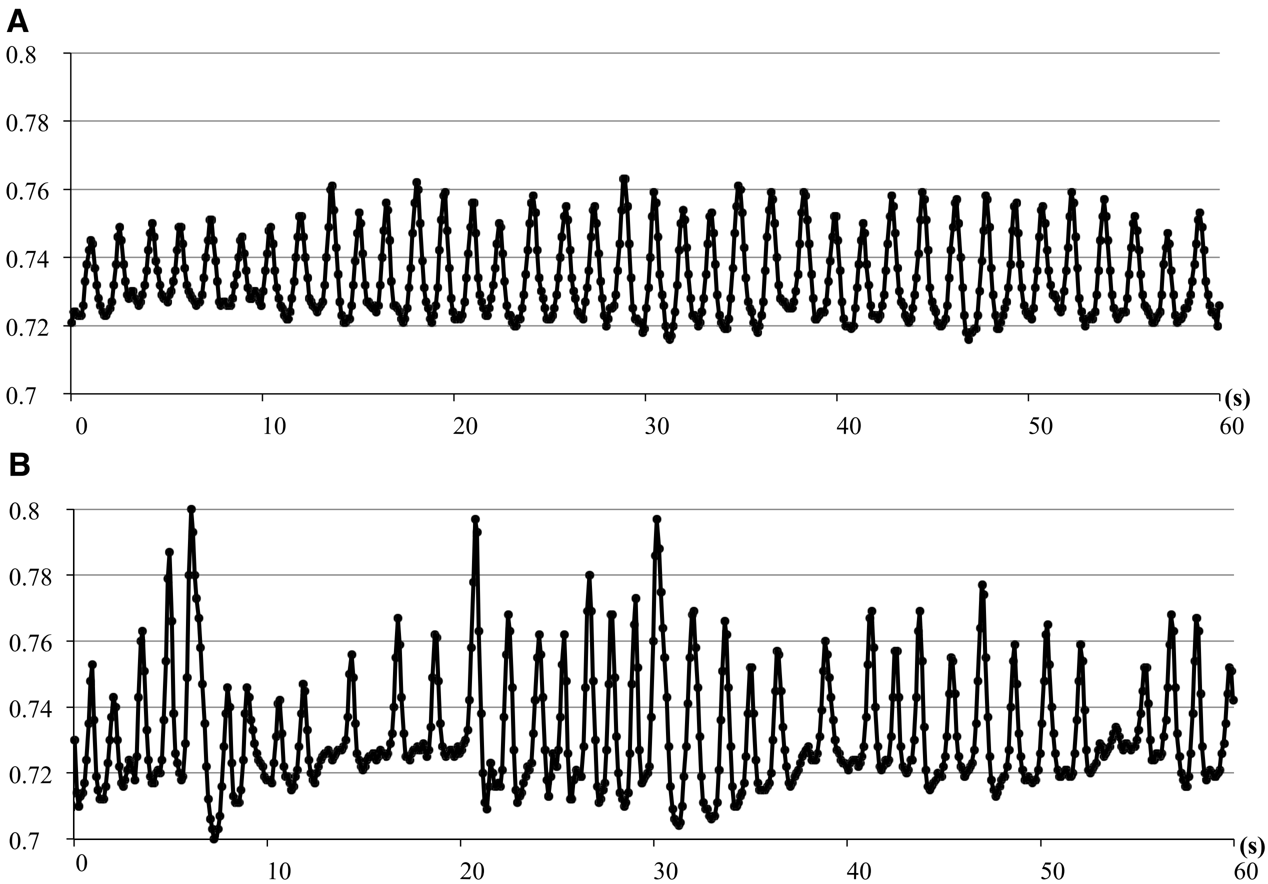

Fig. 1. An example of respiratory movements in a newborn.
A: During quiet sleep. **B**: During active sleep.
Unit of the vertical axis is arbitrary.

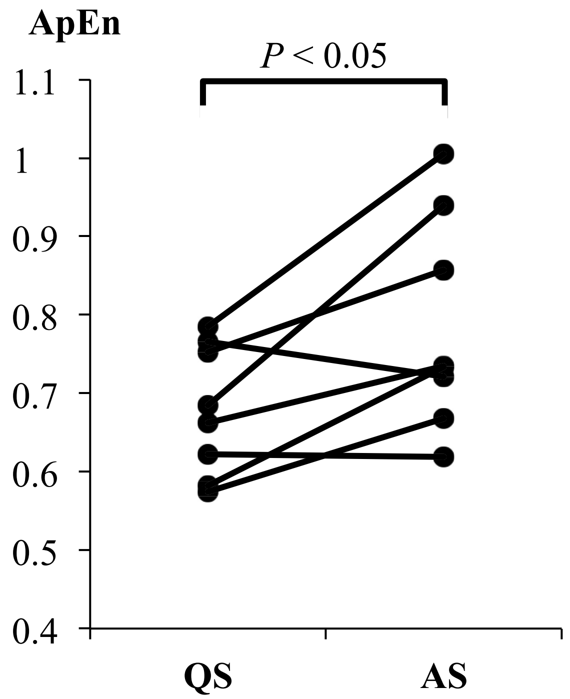

Fig. 2. ApEn of respiratory movements during quiet sleep and active sleep in eight newborns. The values of ApEn during active sleep (AS) were significantly larger than that during quiet sleep (QS) ($P < 0.05$). ApEn, approximate entropy; AS, active sleep; QS, quiet sleep.

DISCUSSION

This is the first study to report that the value of ApEn of respiratory movement in active sleep was significantly larger than that of quiet sleep in healthy newborns, which suggested that the state of respiration was more irregular during active sleep than during quiet sleep. In healthy adults, we have reported that ApEn from respiratory movement during rapid eye movement (REM) sleep was significantly larger than that during sleep stage IV.[4] REM sleep and non-REM sleep are equivalent to active sleep and quiet sleep, respectively, in newborns.[7] Changes in ApEn of respiratory movements during quiet sleep and active sleep in newborns were similar to the changes in non-REM sleep and REM sleep in adults.

One of the major problems during sleep in newborns is sudden infant death syndrome (SIDS), which remains to be the important cause of infant deaths in Japan. It was reported that active sleep occupies more than 50% of the total sleep time in newborns.[8] Sleep apneas in the neonatal period frequently occur during active sleep,[2] and SIDS was found to happen in an abnormal percentage of obstructive sleep apneas.[8] We counted the breathing interval in spite of the small amplitudes in respiratory movement (Fig. 1B), because the respiratory irregularity is one of the features in active sleep of newborns. Although the breathing interval analysis uses only some intervals in a time series, ApEn uses the total data points. Moreover, entropy measurement can estimate the complex systems, including nonlinear deterministic and stochastic.[4–6] In this point, ApEn measurement may be suitable to analyze biological signals. Nonlinear analysis of the ApEn of respiration may be useful for detecting the irregularity of respiration during sleep in newborns, but further study is needed to validate and estimate its clinical usefulness.

The authors declare no conflict of interest.

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