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Statistical Model of the Occurrence of Sleep Apnea

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Abstract: There was limited information on the analysis of sleep disorder especially apnea. Therefore, study on sleep apnea is essential to understand the sleep behavior during the occurrence of apnea. Markov chain analysis particularly suitable to analyze discrete data that involves time. Data on apnea is discrete as it was measured by recording if the apnea events happens during each epoch of sleep. In this study, the Markov chain model is fitted to the apnea and no apnea data to determine the optimum order of the occurrence of apnea using the Akaike's Information Criterion (AIC) and Bayesian Information Criteria (BIC) for each subjects of 14 subjects that has apnea problem. The results indicated that the optimum order varies according to sleep stages and period of sleep. Generally, the higher order of Markov chain models is suggested during light and deep sleep stages. However, it is found that regardless of sleep stages the optimum order of Markov chain model is varies during the first, second, third and fourth quarter period of sleep. The analysis for describing the most appropriate order showed that the third order model is suitable for most subjects. In conclusion, the analysis indicates that the third order of the Markov chain model is the most appropriate order regardless of sleep stages and sleep period.

Key words: Markov chain, apnea, optimum order, sleep stages, AIC, BIC

INTRODUCTION

Throughout the world very little information is known regarding the sleep disorder especially apnea. The work on data recording need much effort as the patient need to go through a polysomnography test. During the polysomnography test, the apnea events and sleep stages is recorded. Apnea is a paused in breathing during sleep. Apnea may be characterized as Obstructive Sleep Apnea (OSA), Central Apnea (CA), Mixed Apnea (MA) and hypopnea. Hypopnea is a partial apnea. Apnea usually last for at least 10 sec and paused in breathing that less than 10 sec is not characterized as apnea (Guilleminault *et al*., 2001). Most of the studies used OSA as it is the frequent events during sleep among apnea patients. In many parts of the world it is partly assumed that apnea is a risk of automobile accident (Barbe *et al*., 1999; Terán-Santos *et al*., 1999). This is because patients with OSA has difficulty to remain focus and give full attention during driving automobiles.

Meanwhile, OSA is found to be associated with hypertension and cardiovascular disease (Strohl, 1996). Moreover, studies have shown that patients with OSA have lower score of quality of life based on the Health Related Quality of Life (HRQOL) questionaire. Stepnowsky *et al*. (2000) reported that HRQOL at lower level especially in those with mild apnea compared to those with moderate to severe apnea. The identification of mild, moderate and severe apnea has been discussed in many studies using the Apnea-Hypopnea Index (AHI). The AHI is the total of apnea and hypopnea divided with number of hour of sleep (Young *et al*., 1999). Lindberg *et al*. (1999) for example has reported that AHI, increased from mild to moderate apnea, during the ten years period of the follow-up study among patients that is not treated. The classification is AHI>5 as mild, AHI(5-30) as moderate and AHI>30 as severe. Moreover, OSA is more serious in older age group (>65 years old) compared to younger age group (<25 years old) and among men compared to women based on AHI.

During sleep there are four sleep stages which is wake, light sleep, deep sleep and Rapid Eye Movement (REM). The sleep stage was recorded for every 30 sec or epoch during sleep. Goh *et al*. (2000) found that time of sleep in each sleep stages is varies. He found that AHI is higher during REM compared to other sleep stages among

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children. Other study by O'Connor *et al.* (2000) in United States showed that occurrence of apnea is more frequent during REM sleep stages especially among women compared to men. However, study by Ware *et al.* (2000) showed that there was no significant difference, the frequency of apnea during REM and other sleep stages between men and women. Therefore, other study have suggested that apnea is more likely influence by cardiovascular disease, body mass index, smoking habits (Lindberg *et al*., 1999; Shahar *et al*., 2001).

Most studies of the characteristics of sleep mentioned above have described simply summary of the sleep and wake cycle, with perhaps the subsequent assumption that the characteristics of sleep is dependent on the previous sleep (Zung *et al*., 1965; Yang and Hursch, 1973). This type of analysis is discussed by Kemp (1986) using a sleep data. Earlier study by Saat and Jemain (2009) have shown that the most suitable distribution to represent hypopnea which is the partial apnea is the Gamma distributions and Weibull distributions. However, based on study by Saat *et al.* (2008) at least 500 observations is required in order to discriminate between both distribution. There was very few study on sleep apnea and effects according to different sleep stages and period of sleep. Therefore, study on sleep disorder especially apnea and the effects on different sleep stages is essential in order to understand the behavior of sleep apnea among adults. In this study, Markov chain model will be used to determine whether the present of apnea is depending on the previous event of apnea. Earlier study by Uysal and Ulus (2007) used Markov chain model to model the threshold of algorithm for a database system.

MATERIALS AND METHODS

We analyze a database comprising 14 subjects with apnea problem. The data was extracted from MIT-BIH database which is http://www.physionet.org/physiobank/database/ which is in 1999 (Ichimaru and Moody, 1999; Goldberger *et al*., 2000). The data comprises of apnea event for every 30 sec or for every epochs. One epoch is equivalent to 30 sec. There are three sleep stages that is included in this study which is light sleep, deep sleep and REM.

Sleep stages were evaluated via the computer program based on the Rechtschaffen and Kales (1968) methods. Stage 1 is drowsiness where people drift in and out of sleep for about 5 to 10 min and can be awakened easily. Stage 2 is light sleep where the eye movements stop. The heart rate slows and body temperature decreases. Stage 3 and 4 is deep sleep and during this stage, there is no eye movement or muscle activity. Rapid Eye Movement (REM), during this stage the breathing becomes more rapid and people usually dream during this stage.

Markov chains models: Let, $X_1, X_2, \ldots, X_{n-n}$ be n binary variables which represent a sequence of the occurrence of apnea and normal events, for a particular individual during the duration of sleep for the length of period of n epochs, indicated as 1 and 0, respectively.

$$X_t = 0, \text{ noapnea}$$
$$= 1, \text{ apnea}$$

and t = 1,2,3,..,n epoch when the events were recorded. Consider that the period of sleep for a particular individual can be divided into many epochs each of length 30 sec (epoch). Since, the occurrence of an event in a particular epoch is dependent on the event which has occurred in the earlier epoch it is suitable to explain the sequence of event using a Markov chain model. The sequence of apnea and normal breathing is assumed to follow a first order Markov Chain (MC) model at time t, when at the time t, X_t depends on previous event X_{t-1}. The occurrence of apnea in a particular epoch is dependent on the previous epoch.

For the first order of Markov chain, the stationary transition probabilities is given by:

$$p_{hi} = P(X_t = i | X_{t-1} = h) h, i = 0,1$$

The conditional transition probabilities for the first order Markov chain at time t is given by:

$$P_{00} = P(X_t = 0 | X_{t-1} = 0)$$
$$P_{01} = P(X_t = 0 | X_{t-1} = 1)$$
$$P_{11} = P(X_t = 0 | X_{t-1} = 1)$$
$$P_{10} = P(X_t = 0 | X_{t-1} = 0)$$

The estimation of the transition probabilities is given by:

$$p_{hi} = n_{hi}/n_{h\bullet}$$

Similarly, for the higher order of Markov chain the transition probabilities can be written as:

Second order Markov chain:

$$p_{hij} = P((X_t = j | X_{t-1} = i, X_{t-2} = h) \; h, i, j = 0,1$$

For the third order of Markov chain:

$$p_{ghij} = P(X_t = j | X_{t-1} = i, X_{t-2} = h, X_{t-3} = g)\ g, h, i, j = 0,1$$

The estimation of the transition probabilities of the second and third order of Markov chain is given by:

$$\hat{p}_{hij} = \frac{n_{hij}}{n_{hi\bullet}}$$

$$\hat{p}_{ghij} = \frac{n_{ghij}}{n_{ghi\bullet}}$$

Optimum order of Markov chain models: In determining the optimum order of Markov chain models, two type of information criteria which is (Akaike's Information Criteria) AIC and Bayesian Information Criteria (BIC) or loss function was used. Both AIC and BIC is calculated by generating the log-likelihood function for the estimated transition probabilities.

The loglikelihood is given by:

$$L_0 = \sum n_j \, ln \frac{n_j}{n\bullet}$$

$$L_1 = \sum n_{ij} \, ln \frac{n_{ij}}{ni\bullet}$$

In this study, we are interested to determine the appropriate order of MC among the set of competing order. Specifically we want to compare between mth and (m-1)th order model. The comparison of the two different MC models to decide on the optimum order say MC models of order kth and rth order where, k<r and k = 0,1,..., r-1, is to form the log likelihood ratio, $\log\theta_{k,r}$. The maximized likelihood ratio statistic is $-2 \log\theta_{k,r}$.
Where:

$$\theta_{k,r} = \frac{L_k(X_1,...,X_n)}{L_r(X_1,...,X_n)} \quad (1)$$

The loss function is denoted by AIC(k) (Chin, 1977), which is given by:

$$AIC(k) = -2 \log\theta_{k,r} - 2v \quad (2)$$

$$v = (A^r - A^k)(A-1)$$

where, v is the degree of freedom with A as the number of states. For this study A = 2 which represent two event which is apnea and normal breathing. Another loss function is based on BIC(k) which can be written as:

$$BIC(k) = -2 \log \theta_{k,r} - v\ln(n) \quad (3)$$

where, n is the sample size. The aim is to find the value of AIC and BIC the minimize the loss function.

Besson's coefficient persistence (R_a): Following the Brookes and Carruthers (1953) the statistical test to examine the persistence of the occurrence of apnea in sequences is Besson's coefficient of persistence (R_a). It was defined as follows:

$$R_a = \frac{1 - P_a}{1 - P_{a|a}} - 1 \quad (4)$$

where, P_a is the probability of the apnea occurrence and $P_{a|a}$ is the conditional probability of the occurrence of apnea given the previous events was apnea.

Fitting Markov chain models: A sequence of apnea events is defined as a period of consecutive epoch say n apnea (no apnea) immediately preceded and followed by apnea (no apnea). In order to compute the frequency distribution of the sequence of apnea using Markov models, the following conditional probabilities will be obtained for the first, second, third and fourth order of Markov chain models. Similar approach is applied for the distribution of the no apnea events. The following notation will be used.

For the first order of Markov chain model the probability of the n apnea is given by:

$$p = (0[n]0) = p_0 p_{01} p_{11}^{n-1} p_{110},\ n = 1,2$$

For the second order of Markov chain model the probability of the one epoch of apnea is given by:

$$p(010) = p_0 p_{01} p_{010}$$

and the probability for more than one apnea following an apnea for the second order of Markov model is given by:

$$p = (0[n]0) = p_0 p_{01} p_{011} p_{11}^{n-2} p_{10},\ n = 2,3$$

For the third order Markov chain model the probability of one and two epoch that has occurrence of apnea is given by:

$$p(010) = p_0 p_{01} p_{010}$$

$$p(010) = p_0 p_{01} p_{011} p_{110}$$

and the probability for more than two epoch that has occurrence of apnea for the third order Markov chain model is given by:

$$p = (0[n]0) = p_0 p_{01} p_{011} p_{0111} p_{11}^{n-3} p_{1110}, \; n = 3,4$$

For the fourth order Markov chain model the probability of one and two epoch that has occurrence of apnea is given by:

$$p(010) = p_0 p_{01} p_{010}$$

$$p(0110) = p_0 p_{01} p_{011} p_{110}$$

$$p(01110) = p_0 p_{01} p_{011} p_{0111} p_{1110}$$

and the probability for more than two epoch that has occurrence of apnea for the third order Markov chain model is given by:

$$p = (0[n]0) = p_0 p_{01} p_{011} p_{0111} p_{01111} p_{11}^{n-4} p_{11110}, \; n = 4,5$$

The Chi-square goodness of fit test will be used to test for the appropriate order of Markov chain models (Mendenhall *et al*., 1999). The test is comparing the observed and the expected distributions of the apnea (no apnea) using the first until fourth order of Markov chain models. The lowest value of Chi-square indicating the most appropriate model. This is because the lowest value of Chi-square between the first, second, third and fourth order is representing the best fit.

RESULTS AND DISCUSSION

Characteristics of the sequence of apnea (no apnea): The conditional probabilities of a apnea (no apnea) event at each 30 sec are estimated for different sleep stages and first, second, third and fourth quarter of sleep . In Table 1, it is found that the conditional probability of an apnea given the previous 30 sec was apnea, P_{aa}, is substantially higher than the probability of apnea, P_a, for all subjects. Furthermore, the difference between the successive conditional probabilities of apnea reduces dramatically and becomes negligible after about 2 or 3 epoch; however, this difference reduces after about 4 or 5 epoch for subject 5,12 and 13.

Similarly, the conditional probabilities of no apnea events show that the probability P_{nn} is substantially higher than P_n. The difference between the successive conditional probabilities of no apnea reduces progressively and becomes negligible after about 5 epochs and about 2 or 3 epoch for subjects for 1 and 2 h, respectively. As expected, the analysis of apnea shows that the conditional probabilities of the apnea, P_{aa}, P_{aaa}, P_{aaaa} and P_{aaaaa} are lower than those of the no apnea P_{nn}, P_{nnn}, P_{nnnn} and P_{nnnnn} during sleep for all subjects.

This may be due to the fact that the apnea seldom lasts for more than five consecutive epoch in most subjects. Thus, it is evident to consider the fifth order Markov (r = 5) as the maximum order of the Markov process. Further analysis of the persistency of the apnea (no apnea) events will be explored by applying Besson's Coefficient of Persistence (BCP). The result indicated that the BCP for subjects 5 is the highest (1.66) when compared to other subjects. However, subject 6 shows the lowest value of BCP (0.01).

The optimum order of Markov chain models: In determining the optimum order of the Markov chain models for a 5-epoch sequence in the during sleep, the minimum loss function obtained from the two decision criteria, namely; the AIC and BIC, will be applied. Table 2 shows that the loss function obtained decision criteria AIC and BIC, consistently shows that the third order is the optimum order regardless of sleep stages. Based on Table 2, negative value of the loss function due to the value of log likelihood is more compared to the penalty. The minimum value of AIC and BIC is used in order to determine the optimum order of the Markov model (2v).

Table 1: Persistency of occurrence of apnea regardless of sleep stages and time of sleep

	Subject												
Pb	1	2	3	4	5	6	7	8	9	10	11	12	13
p_a	0.15	0.24	0.16	0.33	0.44	0.25	0.19	0.81	0.38	0.48	0.35	0.52	0.47
p_{aa}	0.43	0.63	0.41	0.68	0.79	0.56	0.53	0.88	0.59	0.62	0.40	0.77	0.51
p_{aaa}	0.43	0.73	0.41	0.75	0.87	0.49	0.49	0.91	0.54	0.62	0.36	0.78	0.46
p_{aaaa}	0.42	0.73	0.42	0.81	0.91	0.53	0.61	0.92	0.56	0.72	0.38	0.79	0.41
p_{aaaaa}	0.33	0.69	0.33	0.82	0.92	0.62	0.57	0.93	0.62	0.73	0.36	0.79	0.57
p_n	0.85	0.75	0.84	0.67	0.56	0.75	0.81	0.20	0.61	0.52	0.65	0.47	0.52
p_{nn}	0.89	0.88	0.89	0.84	0.84	0.85	0.89	0.61	0.74	0.65	0.67	0.75	0.56
p_{nnn}	0.92	0.90	0.91	0.91	0.92	0.95	0.92	0.89	0.91	0.91	0.83	0.89	0.88
p_{nnnn}	0.93	0.91	0.95	0.93	0.92	0.95	0.94	0.91	0.95	0.95	0.88	0.92	0.92
p_{nnnnn}	0.95	0.91	0.94	0.95	0.93	0.96	0.95	0.93	0.95	0.95	0.88	0.94	0.91
BCP	0.49	1.05	0.42	1.09	1.66	0.01	0.73	1.10	0.58	0.51	0.36	0.08	1.09

Table 2: The loss function BIC(r) for various order of Markov chain, r, m = 4

Subject	Order(r) 0	1	2	3	4
1	-112.25	**-127.366**	-122.876	-108.339	-73.133
2	-49.567	-129.800	**-131.441**	-110.042	-79.372
3	165.309	-29.442	-98.715	**-119.367**	-82.624
4	281.982	-26.775	-128.34	**-133.44**	-95.518
5	129.377	29.593	**-137.213**	-135.657	-90.986
6	18.261	-72.326	-87.419	**-88.471**	-68.122
7	101.211	-51.697	**-127.659**	-117.501	-90.631
8	-9.173	-44.131	-119.288	**-133.239**	-92.148
9	157.502	79.903	-96.012	**-111.511**	-84.243
10	145.530	98.392	-109.442	**-119.557**	-78.198
11	-24.079	-20.099	-126.657	**-128.166**	-84.097
12	53.167	-67.177	**-122.369**	-105.303	-71.149
13	-68.828	-64.772	**-103.149**	-88.682	-66.522

Bold values indicate the minimum

Table 3: Optimum order of Markov chain for apnea event according to AIC and BIC according to sleep stages

	Sleep stages Light		Deep		REM	
Subject	AIC	BIC	AIC	BIC	AIC	BIC
1	5	3	1	1	1	1
2	2	1	-	-	2	1
3	3	2	1	1	4	2
4	3	2	0	0	1	1
5	3	2	0	0	2	1
6	4	0	1	1	-	-
7	3	2	-	-	1	1
8	4	2	0	0	1	1
9	3	3	-	-	1	1
10	4	2	1	0	1	1
11	4	2	-	-	-	-
12	4	0	-	-	-	-
13	3	3	0	2	2	1

As an example, Table 3 shows that the loss function obtained from the AIC and BIC (Eq. 2, 3) consistently shows that the second order is found optimum in almost all the subjects for light sleep stages using BIC. However, for the deep and REM sleep stages the optimum order is less than two based on the BIC the optimum order for the apnea events is found to be slightly lower than the optimum order obtained from AIC. It is also shown that the optimum order estimated by the AIC is either greater or equals to the BIC for most subjects during light sleep and deep sleep.

For the rest of the analysis, Table 4 displays the summary of the optimum order of 5 epoch sequence of apnea and non apnea according to first, second, third and fourth quarter duration of sleep and sleep stages. It can be seen that the optimum order obtained from both, decision criteria varies with sleep stages and hour of sleep. Generally, for both the AIC and BIC and the sleep stages considered, the Markov chain of higher order is found to be optimum for the 25% period of sleep for subject 6 and 11. However, for the 50 and 75% period of

Table 4: Optimum order of Markov chain for apnea event according to AIC and BIC for first, second, third and fourth quarter period of sleep

	First (25%)		Second (50%)		Third (75%)		Fourth (100%)	
Subject	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
1	0	0	0	0	0	0	0	0
2	1	1	2	1	2	1	2	1
3	2	2	3	2	3	0	2	1
4	3	2	2	1	2	2	2	1
5	3	2	2	2	0	0	3	2
6	3	3	1	1	2	2	2	1
7	1	1	3	2	2	2	2	2
8	2	2	3	2	3	3	3	2
9	2	2	3	3	3	3	3	2
10	3	3	3	2	2	2	3	1
11	2	2	2	2	3	0	3	1
12	2	1	2	2	3	2	2	2
13	2	2	2	0	2	2	2	2

Table 5: The value of Chi-square goodness of fit test for various orders of Markov chain models for the distribution of apnea events

Subject	MC1	MC2	MC3	MC4
1	0.831	0.823	**0.822**	0.856
2	4.159	**0.0003**	0.001	0.002
3	10.998	9.526	**0.006**	8.407
4	38.748	**0.0001**	0.0017	6.622
5	6.867	**1.028**	1.007	0.929
6	4.694	2.877	**0.0006**	1.971
7	5.445	0.007	**0.005**	16.945
8	3.498	2.997	**0.244**	0.387
9	9.076	**0.551**	0.685	0.812
10	14.944	15.087	**4.152**	11.239
11	1.325	0.389	**0.192**	3.061
12	0.604	0.692	**0.169**	10.095
13	0.588	**0.137**	0.525	2.912

Bold values indicate the minimum

sleep the optimum order higher than two is found to the optimum order for subject 9 and 10. Moreover, for the fourth quarter period of sleep the optimum order is likely less than three for most subjects. In addition for subject 1 the apnea event is independent with the previous apnea event during all period of sleep. This findings is supported by Katz (1981) indicated that the optimum order based on the AIC was inconsistent and had a tendency to over-estimate the true optimum order, whereas the BIC produced more consistent results.

Table 4 shows that, in general it shows that the second order of Markov chain is the optimum order for describing the distributions of apnea during 25% period of sleep for most subjects except for subject 2,7 and 13 according to BIC. However, during the second, third and fourth period of sleep the optimum order is varies.

The most appropriate order of Markov chain models to explain the apnea (no apnea) using various order of Markov chains is identified through the Chi-square goodness of fit test. Table 5 provides the value of Chi-square regardless of sleep staged and period of sleep, based on the most appropriate order of the first four orders of the Markov chain models indicated as

MC1, MC2, MC3 and MC4 for the distributions of apnea and non apnea for the three selected subjects, respectively. It is also found that a higher order of the Markov chain models (order more than one) are observed to be more appropriate in order to describe the distribution of apnea as shown in Table 5. Regardless of sleep stages, for the three sleep stages it is consistently show that the higher order of Markov chain is found to be appropriate for representing the distribution of apnea for most subjects.

CONCLUSIONS

The information of apnea behavior is important to the medical experts which can be used to make prediction of severity of apnea. The analysis of persistence of apnea (no apnea) add the information of the occurrence of apnea based on the previous epoch. The results based on analysis will provide a more information of the apnea occurrence during sleep. In this study, the Markov chain of various orders were applied on the apnea occurrences among patients in MIT-BIH hospital by considering the period of sleep and different sleep stages.

It can be concluded from this study that the 5 epoch of apnea occurrence varies according to levels of hour of sleep and sleep stages . Generally, for all cases, the results show that the optimum order identified by using AIC is higher compared to BIC. The findings is supported by Jimoh and Webster (1996) and Katz (1981) based on the simulation study that AIC in inconsistent compared to BIC. Meanwhile, the order greater than one is optimum order for most for all period of sleep. However, for the optimum order is higher during light compared to deep and REM sleep stages. This study is supported by study by Goh *et al.* (2000), who claimed that the apnea is more frequent is second hour of sleep compared to first hour of sleep. Their findings indicated that 55% of apnea occurs during REM sleep stages and last period of sleep. They divide the hour of sleep into three periods.

Since, the higher order of Markov chain models is found to be optimum for the light sleep stages, indicating that the results may provide evidence that the higher the order of the chain, the greater the persistence of the apnea (no apnea) events especially for subject 9 and 10. Moreover, for the apnea event for the third order of Markov chain model is found to be the most appropriate order in most subjects regardless of sleep period and sleep stages.

Further analysis could be carried out by including other covariates so that many valuable information could be found and more prediction can be made to understand the behavior of apnea. In the future, it is suggested that the most appropriate probability models by comparing various orders of Markov model with the Bayesian model in representing the severity of apnea by considering the proportions of apnea events for each subject and other severity index such as Apnea-Hypopnea Index (AHI) and Respiratory Disturbance Index (RDI).

Generally the stationary pattern of apnea and non stationary pattern of apnea are difference among subject between sleep stages. This may be due to the health status of the subject. In addition (Bardwell *et al.*, 1999; Guillenimault *et al.*, 2000) found that the occurrence of apnea may be severe among subject that has depression, anger, anxiety and mood disturbance.

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REFERENCES

Barbe, F., J. Pericas, A. Munoz, L. Findley, J.M. Anto and A.G.N. Augusti, 1999. Automobile accidents in patients with sleep apnea syndrome an epidemiological and mechanistic study. Am. J. Respir. Crit. Care Med., 158: 18-22.

Bardwell, W., A.C.C. Berry, S. Ancoli-Israel and J.E. Dimsdale, 1999. Psychological correlates of sleep apnea. J. Psychosomatic Res., 47: 583-596.

Brookes, C.E. and N.C. Carruthers, 1953. Handbook of Statistical Methods in Meterology 1953. Her Majesty's Stationary Office, London, UK., 412.

Chin, E.H., 1977. Modelling daily occurrence process with Markov chain. Water Resour. Res., 13: 949-956.

Goh, D.Y.T., P. Galster and C.L. Marcus, 2000. Sleep architecture and respiratory disturbances in children with obstructive sleep apnea. Am. J. Respir. Crit. Care Med., 162: 682-686.

Goldberger, A.L., L.A.N. Amaral, L. Glass, J.M. Hausdorff and P.C. Ivanov *et al.*, 2000. PhysioBank, physioToolkit and physioNet: Components of a new research resource for complex physiologic signals. Circulation, 101: e215-e220.

Guilleminault, C., Y. Do Kim, S. Chowdhuri, M. Horita, M. Ohayon and C. Kushida, 2001. Sleep and daytime sleepiness in upper airway resistance syndrome compared to obstructive sleep apnoea syndrome. Eur. Respir., 17: 838-847.

Ichimaru, Y. and G.B. Moody, 1999. Development of the polysomnographic database on CD-ROM. Psychiatry Clin. Neurosci., 53: 175-177.

Jimoh, O.D. and P. Webster, 1996. The optimum order of a Markov chain model for daily rainfall in Nigeria. J. Hydrol., 185: 45-69.

Katz, R.W., 1981. On some criteria for estimating the order of Markov chain. Technometrics. 23: 243-249.

Kemp, B. and H.A. Kamphuisen, 1986. Simulation of human hypnograms using a Markov chain model. Sleep, 9: 405-414.

Lindberg, E., A. Elmasry, T. Gislason, C. Janson, H. Bengtsson, J.M.H. Nettelbladt and G. Boman, 1999. Evolution of sleep apnea syndrome in sleepy snorers a population-based prospective study. Am. J. Respir. Crit. Care Med., 159: 2024-2027.

Mendenhall, W., R.J. Beaver and B.M. Beaver, 1999. Introduction to Probability and Statistic. Duxbury Press. Pacific Grove, USA., 614-615.

O'Connor, C., K.S. Thornley, P.J. Hanly, 2000. Gender differences in the polysomnographic. Features of obstructive sleep apnea. Am. J. Respir. Crit. Care Med., 161: 1465-1472.

Rechtschaffen, A. and A.A. Kales, 1968. A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Government Printing Office, NIH Publication No. 204, Washington, DC., USA.

Saat, N.Z.M., A.A. Jemain and S.H.A. Al-Mashoor, 2008. A comparison of weibull and gamma distribution in application of sleep apnea. Asian J. Math. Statist., 1: 132-138.

Saat, N.Z.M. and A.A. Jemain, 2009. Modelling the duration of hypopnea. J. Applied Sci., 9: 2162-2167.

Shahar, E.C., S. Whitney, E. Redline, A. Lee and F. Newman *et al*., 2001. Sleep disordered breathing and cardiovascular disease: Cross-sectional results of the sleep heart health study. Am. J. Respiratory Clin. Care Med., 163: 19-25.

Stepnowsky, C., S. Johnson, J. Dimsdale and J.S. Ancoli-Israel, 2000. Sleep apnea and health-related quality of life in African-American elderly. Ann. Behav. Med., 22: 116-120.

Strohl, K.P., 1996. Diabetes and sleep apnea. Sleep, 19: 225-228.

Terán-Santos, J., A. Jimenez-Gomez and J. Cordero-Guevara, 1999. The association between sleep apnea and the risk of traffic accidents. NEJM., 340: 847-851.

Uysal, M. and T. Ulus, 2007. A threshold based dynamic data allocation algorithm-A Markov chain model approach. J. Applied Sci., 7: 165-174.

Ware, J.C., R.H. McBrayer and J.A. Scott, 2000. Influence of sex and age on duration and frequency of sleep apnea events. Sleep, 23: 165-170.

Yang, M.C.K. and C.J. Hursch, 1973. The use of the semi-Markov for describing sleep patterns. Biometrics, 29: 667-676.

Young, T., M. Palta, J. Dempsey, J. Skatrud, S. Weber and S. Badr, 1999. The Occurrence of sleep disordered breathing among middle-aged adults. N. Eng. J. Med., 328: 1230-1235.

Zung, W., T. Naylor, C. Gianturco and W.P. Wilson, 1965. Computer simulation of sleep EEG patterns using a Markov chain model. Biol. Psychiat., 8: 335-355.