Sleep Breath (2015) 19:1051–1056
DOI 10.1007/s11325-014-1103-9

ORIGINAL ARTICLE

The sleep characteristics in symptomatic patients with Duchenne muscular dystrophy

Karen Tieme Nozoe · Gustavo Antônio Moreira · José Rodolfo Corradini Tolino · Márcia Pradella-Hallinan · Sergio Tufik · Monica Levy Andersen

Received: 12 May 2014 / Revised: 24 November 2014 / Accepted: 15 December 2014 / Published online: 8 January 2015

Abstract
Background Duchenne muscular dystrophy (DMD) causes serious health consequences that include impairment of the respiratory system and sleep. The aim of our study is to investigate the sleep architecture and respiratory profile during sleep of symptomatic patients with DMD without ventilatory support.
Methods We evaluated polysomnography (PSG) of boys with DMD (n=44) and a control group (n=79) with sleep complaints that was matched in age but without neuromuscular disease.
Results DMD patients presented sleep impairments when compared with the control group in terms of decreased sleep efficiency (72.4±1.9 vs 80.3±1.4 %, P=0.002) and increased apnea-hypopnea index (AHI) during nonrapid eye movement (NREM) sleep (1.6±0.3 vs 0.3±0.2/h, P=0.003). The main changes were observed during rapid eye movement (REM) sleep: an increase in REM sleep latency (202.2±11.8 vs 152.3 ±8.6 min, P<0.001), a reduced percentage of REM sleep (13.1±0.9 vs 17.9±0.7 %, P=0.001), and exacerbation of AHI (8.7±1.5 vs 1.0±1.1 events/h, P=0.001). There was an increase in the total number of apneas, especially obstructive apneas (6.8±1.9 vs 0.8±1.3, P=0.013).
Conclusions The sleep and respiratory profile during sleep of patients with DMD are compromised. The results suggest that these changes reflect the muscle weakness inherent in DMD and are demonstrated mainly during REM sleep. Thus, the use of PSG is important to identify sleep-disordered breathing at an early stage, before deciding when to introduce noninvasive respiratory support for prevention of respiratory complications.

K. T. Nozoe · G. A. Moreira · J. R. C. Tolino · M. Pradella-Hallinan · S. Tufik · M. L. Andersen (✉)
Department of Psychobiology, Universidade Federal de São Paulo, São Paulo, SP, Brazil
e-mail: ml.andersen12@gmail.com

Keywords Duchenne muscular dystrophy · Polysomnography · Sleep-disordered breathing · REM sleep

Abbreviations

AHI	Apnea-hypopnea index
BMI	Body mass index
DMD	Duchenne muscular dystrophy
EEG	Electroencephalogram
NREM	Nonrapid eye movement
OSAS	Obstructive sleep apnea syndrome
PSG	Polysomnography
REM	Rapid eye movement
SDB	Sleep-disordered breathing
SpO_2	Oxygen saturation

Introduction

Duchenne muscular dystrophy (DMD) is a genetic disease with high mortality in humans, affecting approximately 1 in every 3500 live male births. This disease is caused by a mutation in the gene encoding a 427-kDa cytoskeletal protein, dystrophin, which is fundamental for the structure and function of muscle tissue [1]. This mutation causes reduction or absence of dystrophin, particularly in cardiac and skeletal muscle, thus compromising muscle function. This leads to a progressive inability to walk in the first decade of life, followed by impairment of the respiratory system in the second decade. In some cases, the pulmonary impairment is preceded by clinical symptoms, such as morning headaches, hypersomnolence, lethargy, fatigue, nonrestorative sleep, and attention deficits [2, 3]. These symptoms may be mild and go

undetected, compromising the health and quality of life. When noninvasive ventilation is not initiated appropriately, the patient may die prematurely. It should be emphasized that the major cause of death in these patients is respiratory failure due to significant loss of respiratory muscle strength, along with a reduction in lung and chest wall compliance.

This weakness of the respiratory muscles is responsible for the development of sleep-disordered breathing (SDB), which can be either obstructive sleep apnea or sleep hypoventilation. Sleep plays an important role in DMD, not only because it is essential to physiological homeostasis, but also because DMD patients are highly susceptible to respiratory abnormalities during sleep. It is estimated that approximately one quarter of DMD patient deaths occur during the night unexpectedly [4]. Approximately 27 to 62 % of children [5] and 36 to 53 % of adults [6, 7] with a neuromuscular disease have at least one type of SDB. Hence, nocturnal tests are highly relevant, as the first signs of respiratory failure are perceived during sleep, especially rapid eye movement (REM) sleep [7, 8]. Thus, nocturnal tests can provide early detection of respiratory impairment and, consequently, early intervention. The aims of this study were to determine the prevalence of sleep disorders in patients with DMD who presented sleep and/or respiratory complaints and compare them with a nonsnoring and nonneuromuscular group of patients who underwent polysomnography (PSG) for other reasons (parasomnia) in our Sleep Institute.

Methods

Subjects

A sample of subjects with DMD was selected from the database of the Sleep Institute, São Paulo, Brazil. The database contains PSG data of adults and children and approval was given to use the relevant data for this research. There were 339 PSG recordings of children and adolescents with some form of neuromuscular disease. We selected only patients with DMD, leaving 44 male patients, aged 7–19 years (13.2± 2.8), who were evaluated and treated appropriately at the neuromuscular outpatient clinic of the Sleep Institute. The confirmation of the diagnosis of DMD was determined by medical history associated to electroneuromyography, muscle biopsy, and/or DNA mutation analysis. The patients' doctors had recommended PSG to assess respiratory impairment, and it was used as one tool to determine the point of initiation of ventilatory support. These patients had at least one symptom suggestive of SBD, such as dyspnea, fatigue, morning headache, hypersomnolence, snoring, witness apnea, or mood changes. For the control group, 79 polysomnographic results were selected from a database. Subjects were chosen to match the DMD patients on age, 6–19 years (11.8±2.9), and sex (male). All were symptomatic at the time of undergoing PSG for a variety of sleep complaints, such as confusional arousal and sleep walking. However, no control subjects were referred for snoring and none had any type of neuromuscular disease. Thus, the control group represents PSG-negative subjects. All patients referred to the Sleep Institute gave their informed consent to provide data for the research.

Nutritional status was classified (malnourished, eutrophic, overweight, and obese) based on body mass index (BMI) for age, in accordance with the criteria established by the Centers for Disease Control and Prevention (CDC) for children 2 to 20 years old (5–95th percentile) [9].

Polysomnography

All subjects underwent baseline clinical PSG for a single night. Sleep studies were staged by three certified pediatric sleep experts. Polysomnography was performed overnight in a dark and quiet environment. The following parameters were measured and recorded on the PSG system (Alice, Philips/Respironics, Murrysville, PA, USA): electroencephalogram (EEG) (C3/A1, C4/A2, O1/A2, O2/A1), right and left electrooculogram, submental electromyogram (EMG), tibial EMG, electrocardiogram, oronasal airflow (three-pronged thermistor), nasal pressure transducer (Pro-Tech, WA, USA), chest and abdominal wall motion (piezoelectric transducers), body position, percutaneous oxygen saturation (SpO_2) by pulse oximetry (Ohmeda, Biox 3740 Louisville, CO, USA), oximeter waveform, and body position. End-tidal carbon dioxide ($ETCO_2$) was performed by CO2SMO Capnography (Novametrix, USA). Subjects were also monitored and recorded on videotape with the use of an infrared video camera and were continuously observed by a polysomnographic technician. Sleep architecture was assessed by standard techniques [10]. Arousals were defined as recommended by the American Sleep Disorders Association [11]. Briefly, an arousal was defined as an abrupt shift in EEG to alpha frequencies (8–13 Hz) or frequencies >16 Hz for a minimum of 3 s. During REM sleep, arousals were scored if the change in EEG was accompanied by a concomitant increase in the amplitude of the submental EMG signal. Obstructive apneas were defined as the presence of chest and/or abdominal motion in the absence of airflow. Mixed apnea was defined as the absence of airflow for at least two breaths that is associated with absent inspiratory effort in one portion of the event, followed by resumption of inspiratory effort in the other portion of the event, regardless of which comes first [11]. As children have a higher respiratory frequency than adults and frequent desaturation even with short apneas, all obstructive apneas >2 breaths in duration were counted [12]. Hypopneas were defined as a decrease in the oronasal airflow >50 %, associated with paradoxical chest wall motion, a change in $ETCO_2$ waveform, oxygen desaturation >3 %, or an arousal. Apnea-

hypopnea index (AHI) was defined as the number of obstructive apneas, mixed apneas, and hypopneas per hour of sleep. Obstructive apnea index was defined as the number of obstructive apneas and mixed apneas per hour of sleep. The SpO_2 nadir and mean SpO_2 were determined. SpO_2 measurements associated with a poor pulse waveform were discounted. As obstructive sleep apnea syndrome (OSAS) in children differs from that in adults, age-specific criteria were used for diagnosis. Mean wake, REM, and nonrapid eye movement (NREM) sleep $ETCO_2$ as well as peak $ETCO_2$ were determined. Polysomnography was considered normal if there was absent of snoring, an obstructive apnea index $\leq$1/h, AHI $\leq$1.5/h for children and AHI <5 for adolescents (>13 years), SpO_2 did not fall below 92 %, and $ETCO_2$ is not >50 mmHg for >25 % total sleep time.

Statistical analysis

For statistical analysis, we used the software Statistical Package for the Social Sciences (SPSS®) version 19.0.0. The comparison between groups was performed using the analysis of covariance (ANCOVA). The samples were tested for normality and homogeneity. For nonnormal variables, *Z*-score tests were performed. The variables age and BMI were used as covariates. These variables were adjusted, but did not show any significant difference. The age distribution was bimodal, with boys between 6 and 12 years and boys aged 13–19 years. All results are presented as mean±standard error (SE). Values were considered significant when $P<0.05$.

Results

The main demographic data of the individuals with DMD and the control group are presented in Table 1. After statistical analysis adjusted for age and BMI, the results showed that patients with DMD have abnormalities in sleep quality (Table 2). Although the subjects in both groups (control vs DMD) have similar total sleep time (mean 380 vs 350 min), sleep architecture differs in some aspects. DMD individuals had a worse sleep efficiency (72.4±1.9 vs 80.3±1.4 %, $F_{1,\ 119}=10.07$, $P=0.002$) and a reduction in the number of sleep stage changes (56.3±3.0 vs 65.9±2.2, $F_{1,\ 119}=6.17$, $P=0.014$) compared to controls. A significant increase was observed in the apnea-hypopnea index during NREM sleep in DMD patients compared to the control (1.6±0.3 vs 0.3±0.2/h, $F_{1,\ 119}=9.43$, $P=0.003$). However, most of the changes were found during REM sleep, including increases in REM sleep latency (202.2±11.8 vs 152.3±8.6 min, $F_{1,\ 119}=11.07$, $P<0.001$), reduction of the percentage of REM sleep (13.1±0.9 vs 17.9±0.7 %, $F_{1,\ 119}=14.53$, $P=0.001$), and increases in AHI (8.7±1.5 vs 1.0±1.1/h, $F_{1,\ 119}=13.49$, $P=0.001$).

Table 1 Demographic data of the individuals of the control and Duchenne muscular dystrophy groups

Variable	Frequency (%)	
	Control group *N* (%)	DMD group *N* (%)
Age group (years)		
1–12	48 (60.8)	17 (38.6)
13–19	31 (39.2)	27 (61.4)
Nutritional status		
Malnourished	15 (19.0)	6 (13.6)
Eutrophic	31 (39.2)	12 (27.3)
Overweight	12 (15.2)	16 (36.4)
Obese	21 (26.6)	10 (22.7)

DMD Duchenne muscular dystrophy

With respect to respiration, patients with DMD showed a significant increase in the total number of apneas, mainly obstructive apneas (6.8±1.9 vs 0.8±1.3, $F_{1,\ 119}=6.31$, $P=0.013$). Most obstructive apneas were associated with bradycardia (2.7±0.9 vs 0.3±0.7, $F_{1,\ 119}=3.97$, $P=0.049$) and oxygen desaturation (5.6±1.8 vs 0.6±1.3, $F_{1,\ 119}=4.71$, $P=0.032$) ((Table 3). Furthermore, mean heart rate was higher in the DMD patients across all stages: during wakefulness (98.4±2.7 vs 83.0±1.9, $F_{1,\ 119}=20.83$, $P=0.001$), REM sleep (92.0±3.0 vs 73.0±2.2, $F_{1,\ 119}=24.69$, $P=0.001$), and NREM (88.7±3.2 vs 71.7±2.3, $F_{1,\ 119}=17.73$, $P=0.001$). Of the DMD group, eight children (18 %) were found to have OSAS, six (14 %) had $SpO_2<90$ % for more than 5 min during REM sleep, and four (9 %) had $SpO_2<90$ % for more than 5 min in NREM sleep. No subjects in the control group, with similar age and BMI, had these conditions. In DMD subjects, the

Table 2 Macrostructure of sleep found in the control and Duchenne muscular dystrophy groups

Parameters	Control	DMD	*P*
Total sleep time (min)	378.7±7.9	353.1±10.8	0.063
Sleep efficiency (%)	80.3±1.4	72.4±1.9*	0.002
Sleep stage changes (*n*)	65.9±2.2	56.3±3.0*	0.014
Sleep latency (min)	35.7±5.3	51.1±7.3	0.095
REM sleep latency (min)	152.3±8.6	202.2±11.8*	0.001
Wake after sleep onset (min)	48.8±5.3	74.0±7.2*	0.007
Arousal index (*n*/h)	15.0±7.2	7.1±9.8	0.532
Stage 1 of NREM sleep (%)	2.2±0.2	1.6±0.3	0.146
Stage 2 of NREM sleep (%)	50.7±1.1	54.0±1.5	0.082
Slow wave sleep (%)	28.9±0.9	30.8±1.2	0.216
REM sleep (%)	17.9±0.7	13.1±0.9*	0.001

The values were expressed mean and standard error

DMD Duchenne muscular dystrophy, *REM* rapid eye movement

*Results that obtained significance of $P<0.05$

Table 3 Respiratory events during sleep found in the control and Duchenne muscular dystrophy groups

Parameters	Control	DMD	*P*
Apneas (*n*)	1.3±1.4	7.3±1.9*	0.015
Hypopneas (*n*)	1.4±1.5	9.6±2.1*	0.002
Obstructive apneas (*n*)	0.8±1.3	6.8±1.9*	0.013
Central apnea (*n*)	0.4±0.13	0.4±0.18	0.939
Mixed apnea (*n*)	0.1±0.1	0.2±0.1	0.458
Total events (*n*)	2.7±2.6	17.0±3.5*	0.002
Obstructive apnea with bradycardia (*n*)	0.3±0.7	2.7±0.9*	0.049
Central apnea with bradycardia (*n*)	0.06±0.05	0.2±0.06	0.158
Number of hypopnea with bradycardia	0.2±0.7	3.0±0.9*	0.014
Number of obstructive apnea with desaturation	0.6±1.3	5.6±1.8*	0.032
Number of central apnea with desaturation	0.2±0.09	0.3±0.1	0.862
Number of hypopnea with desaturation	0.8±1.2	7.6±1.7*	0.002
Hypopnea index (*n*/h)	0.2±0.2	1.6±0.3*	0.001
NREM AHI (*n*/h)	0.3±−0.2	1.6±0.3*	0.003
REM AHI (*n*/h)	1.0±1.1	8.7±1.5*	0.001

The values were expressed mean and standard error

DMD Duchenne muscular dystrophy, *REM* rapid eye movement, *NREM* nonrapid eye movement, *AHI* apnea-hypopnea index

*Results that obtained significance of $P<0.05$

Table 4 Cardiovascular parameters and saturation during sleep found in the control and Duchenne muscular dystrophy groups

Parameters	Control	DMD	*P*
Mean wake heart rate (bpm)	83.0±1.9	98.4±2.7*	0.001
Mean REM heart rate (bpm)	73.0±2.2	92.0±3.0*	0.001
Mean NREM heart rate (bpm)	71.7±2.3	88.7±3.2*	0.001
NREM desaturation index (*n*/h)	0.8±0.4	2.4±0.5*	0.015
Mean wake SpO_2 (%)	96.6±0.1	96.3±0.2*	0.001
Mean REM SpO_2 (%)	96.6±0.2	95.6±0.2*	0.001
Mean NREM SpO_2 (%)	96.5±0.2	95.8±0.2*	0.016
Wake SpO_2<90 % (min)	0.3±0.2	0.6±0.3	0.302
REM SpO_2<90 % (min)	0.4±0.3	0.9±0.4	0.448
NREM SpO_2<90 % (min)	0.6±0.7	1.8±1.0	0.382

The values were expressed mean and standard error

DMD Duchenne muscular dystrophy, *REM* rapid eye movement, *NREM* nonrapid eye movement, *SpO_2* oxygen saturation

*Results that obtained significance of $P<0.05$

mean $ETCO_2$ was 33.4 mmHg in wakefulness, 34.7 mmHg in REM sleep, and 31.0 mmHg in NREM sleep. The mean of the peak of $ETCO_2$ was 41.2 mmHg. Six of these subjects had $ETCO_2$>50 mmHg during wakefulness and five had $ETCO_2$ above 50 mmHg during REM and NREM sleep. No subjects had $ETCO_2$>50 for more than 10 % of total sleep time. In general, these DMD patients showed mild hypercapnia; only two patients showed hypercapnia without the presence of sleep apnea. Furthermore, there were four patients who had hypoxemia during REM sleep and three patients during NREM sleep (Table 4).

Discussion

We found that children and adolescents with DMD have impaired sleep patterns, as well as impaired heart and breathing patterns during sleep. The most notable changes occurred during REM sleep. Overall, the latency to sleep onset was preserved; however, there was a higher latency to REM sleep, as well as a decrease in the percentage of REM sleep. Compared to controls, DMD patients showed a worse sleep efficiency. These changes in the sleep architecture of patients were mainly due to respiratory impairment.

As previously noted, DMD patients have a high incidence of respiratory disorders during sleep, particularly obstructive sleep apnea and respiratory abnormalities during sleep. These disorders result from progressive muscle weakness. Several changes in central respiratory control, airway resistance, and muscular contractility usually occur during sleep [13]. During REM sleep in particular, and especially during the bursts of rapid eye movements, breathing is very irregular [14]. Therefore, it is during REM sleep that patients with muscular weakness are more likely to have respiratory irregularities. The present study observed changes in sleep pattern and respiration during REM sleep in patients with DMD.

Previous studies have reported that children affected by DMD have alterations in sleep, mainly obstructive respiratory events [8], SDB (frequency of about 31 %), OSAS (31 % in the first decade of life), and hypoventilation (32 % in the second decade of life) [7]. Recently, studies have also shown disorders in initiating and maintaining sleep, sleep hyperhidrosis [15], high total arousal index, high percentage of superficial sleep [16], and excessive daytime sleepiness [17]. In addition, because of the consequences of DMD, reduction in both sleep efficiency and total sleep time can be expected [18, 19]. In the present study, we found a significant reduction of sleep efficiency (72.5 %) in the group with DMD, which is consistent with a previous study which reported a mean sleep efficiency of 77 % [7]. However, other studies have reported sleep efficiencies of 93 % [20] and 82 % in DMD patients [2]. We observed increased REM sleep latency (201.7 min), while Khan and Heckmatt [20] reported an average of 157 min. These differences observed may be related to the type of methodology, since our study was performed at the Institute and constantly monitored by a technician, while in other studies, PSG was conducted in the home of the subject. Additionally, another important factor that should be taken into consideration is otolaryngological problems because they could have an influence in the context of OSAS and may

consequently impact the efficiency of sleep. Finally, the diagnosis of OSAS should also be taken into consideration, as sleep fragmentation caused by OSAS may influence sleep efficiency.

In a small sample of children and adolescents with DMD, we showed that 8 out of 44 (18 %) had sleep-disordered breathing. This indicates that DMD patients have a higher rate of obstructive sleep apnea, which is in line with previous studies. Suresh and colleagues [7] observed a 30 % prevalence of OSAS in children, while Khan and Heckmatt [20] found 60 % obstructive, 30 % central, and 10 % mixed apnea. However, Barbé and colleagues [2] reported a higher incidence of central apnea (85 %), in contrast to other studies and our findings. It is noteworthy that both central and obstructive events should be evaluated, as, due to the muscle weakness present in these patients, these events can be easily misdiagnosed. This can occur because the respiratory mechanics is compromised in DMD patients, mainly with shallow breaths, and obstructive apnea can be misdiagnosed as central apnea [21]. We did not use either esophageal pressure, or induced pletysmography, which is a limitation of the current study. In fact, few studies used esophageal pressure monitoring.

Regardless of the type of apnea, it is worth emphasizing the importance of diagnosing these events, because respiratory abnormalities during sleep, identified primarily through PSG, precede daytime respiratory failure [22]. Beyond this factor, nocturnal evaluation is indispensable because patients with DMD generally have a decrease in vital capacity and normal gas exchange during wakefulness, but have hypercapnia and severe oxygen desaturation solely during sleep [20]. Thus, the diagnosis of respiratory abnormalities during sleep is useful for monitoring disease progression and indicates risk for daytime respiratory failure [23]. In addition, persistent hypoventilation and events of hypopneas associated with desaturations during REM sleep may be of particular relevance as early warning signs [5]. In DMD, as with all neuromuscular diseases, hypoventilation is generally observed [24]. However, we did not find hypoventilation in the present study, possibly because the disease in these patients was not severe, since they are still young patients and usually this is observed in older patients.

The incidence and severity of SDB and hypoxemia is greater in older DMD patients. However, some younger individuals with DMD also have considerable respiratory impairment, especially during REM sleep [7]. In our study, although most of the sample consisted of older patients, we found that eight younger DMD subjects (18 % of the total of sample with mean 10 to 17 years old) had OSAS. Thus, the monitoring and evaluation of sleep in individuals of all ages is crucial to the detection and treatment of nocturnal hypoxemia and/or hypercapnia. When left untreated, this condition progresses to daytime respiratory failure and later to pulmonary hypertension and *cor pulmonale* [8]. It has been shown that in patients with daytime hypercapnia without respiratory intervention, survival is only approximately 9.7 months after hypercapnia develops [25]. Therefore, PSG, beyond simply elucidating clinical signs, is important in the diagnosis of respiratory events and indicating the need for intervention of noninvasive ventilatory support. Home oximetry is a less expensive way to detect overnight oxygen abnormalities; however, it does not differentiate OSAS from sleep hypoventilation. This finding has implications for future management, as younger DMD children with OSAS might benefit from tonsillectomy instead of positive pressure ventilation.

The benefit of the use of ventilatory support is easily seen with the decrease in symptoms caused by SDB (such as excessive daytime sleepiness and morning headaches) and mainly by a gain of approximately 5 years of life when compared with those who do not receive respiratory assistance [26]. Knowing that in patients with DMD respiratory muscle weakness is inevitable, and the various consequences that occur alongside the progression of the disease, appropriate and timely treatment of respiratory problems is essential. Thus, a constant and individual evaluation is necessary since the time and severity of events vary in each individual. In this sense, it is possible to treat SDB, reduce the risk of respiratory failure, the leading cause of mortality in patients with DMD, and extend the quality of life of these patients.

These findings have to take into account some study limitations. This a retrospective study, so sleep staging may vary depending on the scorer and the absence of relevant data due to missing reports. There is a lack of information on medication that might affect sleep, such as corticosteroids. Some of the sleep architecture abnormalities may be due to the presence of sleep-disordered breathing in DMD group. Despite some limitations in the study, the results demonstrate that the sleep of children and adolescents with DMD is impaired, even in young patients. Given the existence of a large prevalence of sleep disruption in patients with DMD, as demonstrated in this study, and knowing its health consequences, it is extremely important to perform constant sleep monitoring. The detection of SDB is relevant for identifying the point of introduction for noninvasive ventilatory support and to set the parameters of the positive pressure therapy, which improves quality of life and increases the survival of these patients.

Conclusions

This study demonstrates that the group of DMD patients exhibited a high frequency of sleep-related breathing disorders and alterations in REM sleep pattern, when compared to the children and adolescents without neuromuscular disease. Thus, it is essential that symptomatic patients with DMD be evaluated using PSG recording.

Acknowledgments This work was supported by grants from Associação Fundo de Incentivo a Pesquisa (AFIP), the São Paulo Research Foundation (FAPESP grant #14/08067-0 to KTN), and CNPq. MLA and ST are recipients of the CNPq fellowship.

Conflict of interest Neither of the authors have any conflict of interest to disclose. We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

References

1. Blake DJ, Weir A, Newey SE, Davies KE (2002) Function and genetics of dystrophin and dystrophin-related proteins in muscle. Physiol Rev 82:291–329
2. Barbé F, Quera-Salva MA, McCann C, Gajdos P, Raphael JC, De Lattre J, Agustí AG (1994) Sleep-related respiratory disturbances in patients with Duchenne muscular dystrophy. Eur Resp J 7:1403–1408
3. Sarnat HB (2008) Neuromuscular disorders. In: Kliegman RM (ed) Muscular dystrophies (Nelson textbook of pediatrics). Saunders, Philadelphia, pp 2531–2567
4. Rideau Y, Gatin G, Bach J, Gines G (1983) Prolongation of life in Duchenne's muscular dystrophy. Acta Neurol (Napoli) 5:118–124
5. Kirk VG, Flemons WW, Adams C, Rimmer KP, Montgomery MD (2000) Sleep-disordered breathing in Duchenne muscular dystrophy: a preliminary study of the role of portable monitoring. Pediatr Pulmonol 29:135–140
6. Labanowski M, Schmidt-Nowara W, Guilleminault C (1996) Sleep and neuromuscular disease: frequency of sleep-disordered breathing in a neuromuscular disease clinic population. Neurology 47:1173–1180
7. Suresh S, Wales P, Dakin C, Harris MA, Cooper DGM (2005) Sleep-related breathing disorder in Duchenne muscular dystrophy: disease spectrum in the paediatric population. J Paediatr Child Health 41:500–503
8. Smith PE, Calverley PM, Edwards RH (1988) Hypoxemia during sleep in Duchenne muscular dystrophy. Am Rev Respir Dis 137:884–888
9. Centers for Disease Control and Prevention (CDC) (2000). Clinical growth charts. http://www.cdc.gov/growthcharts/clinical_charts.htm. Accessed 12 Jan 2014
10. Rechtschaffen A, Kales A (1968) A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Brain Information Service/Brain Research Institute, Los Angeles, pp 246–247
11. Iber C, Ancoli-Israel S, Chesson AL Jr, Quan SF, for the American Academy of Sleep Medicine (2007) The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, 1st edn. American Academy of Sleep Medicine, Westchester
12. Consensus Conference (1992) EEG arousals: scoring rules and examples: a preliminary report from the Sleep Disorders Atlas Task Force of the American Sleep Disorders Association. Sleep 15:173–184
13. McNicholas WT (1997) Impact of sleep in respiratory failure. Eur Respir J 10:920–933
14. Millman RP, Knight H, Kline LR, Shore ET, Chung DC, Pack AI (1988) Changes in compartmental ventilation in association with eye movements during REM sleep. J Appl Physiol 65:1196–1202
15. Bloetzer C, Jeannet PY, Lynch B, Newman CJ (2012) Sleep disorders in boys with Duchenne muscular dystrophy. Acta Paediatr 101:1265–1269
16. Polat M, Sakinci O, Ersoy B, Sezer RG, Yilmaz H (2012) Assessment of sleep-related breathing disorders in patients with Duchenne muscular dystrophy. J Clin Med Res 4:332–337
17. Dhand UK, Dhand R (2006) Sleep disorders in neuromuscular diseases. Curr Opin Pulm Med 12:402–408
18. David WS, Bundlie SR, Mahdavi Z (1997) Polysomnographic studies in amyotrophic lateral sclerosis. J Neurol Sci 152:S29–35
19. Ferguson KA, Strong MJ, Ahmad D, George CF (1996) Sleep-disordered breathing in amyotrophic lateral sclerosis. Chest 110:664–669
20. Khan Y, Heckmatt JZ (1994) Obstructive apnoeas in Duchenne muscular dystrophy. Thorax 49:157–161
21. Eikermann M, Jordan AS, Chamberlin NL, Gautam S, Wellman A, Lo YL, White DP, Malhotra A (2007) The influence of aging on pharyngeal collapsibility during sleep. Chest 131:1702–1709
22. Manni R, Zucca C, Galimberti CA, Ottolini A, Cerveri I, Bruschi C, Zoia MC, Lanzi G, Tartara A (1991) Nocturnal sleep and oxygen balance in Duchenne muscular dystrophy. A clinical and polygraphic 2-year follow-up study. Eur Arch Psychiatry Clin Neurosci 240:255–257
23. Hukins CA, Hillman DR (2000) Daytime predictors of sleep hypoventilation in Duchenne muscular dystrophy. Am J Respir Crit Care Med 161:166–170
24. Chebbo A, Tfaili A, Jones SF (2011) Hypoventilation syndromes. Med Clin North Am 95:1189–1202
25. Ragette R, Mellies U, Schwake C, Voit T, Teschler H (2002) Patterns and predictors of sleep disordered breathing in primary myopathies. Thorax 57:724–728
26. Consensus Conference (1999) Clinical indications for noninvasive positive pressure ventilation in chronic respiratory failure due to restrictive lung disease, COPD, and nocturnal hypoventilation—a consensus conference report. Chest 116:521–534