# Chapter 2
# Evaluation Instruments for Sleep Disorders: A Brief History of Polysomnography and Sleep Medicine

**José Haba-Rubio and Jean Krieger**

**Abstract** Sleep is a vital biological function and we currently know that sleep disorders are highly prevalent in the population. The history of the development of sleep science and sleep medicine is inextricably tied to the development of polysomnography, used as a means to assess, objectively and in a reproducible way, sleep and wakefulness. Over the past 50 years, technologic advances and scientific progress have permitted huge improvements in the systems used to record sleep. Furthermore, major advances in sleep science and pathology are linked with improvements in the methods of recording and analyzing sleep. It can be asserted that the development of polysomnography transformed sleep research from a speculative area to an experimental science. This chapter has been organized to briefly relate the major developments in sleep medicine and to summarize the evolution of polysomnography.

**Keywords** Sleep medicine • History • Polysomnography

Sleep and dreams have played a central role in the culture of humankind and has fascinated people for a very long time. Sleep occupies a third of our lives; every night the mystery of sleep unfolds before each of us. However, it was not until recently that we had the opportunity to study sleep from a scientific point of view, in other words, beyond the observations of philosophers, poets and prophets.

J. Haba-Rubio, M.D.
Center for Investigation and Research in Sleep, Centre Hospitalier Universitaire Vaudois/Université de Lausanne, Lausanne, Switzerland

J. Krieger, M.D., Ph.D. (✉)
Faculté de Médecine, Université Louis Pasteur, Strasbourg, France
e-mail: krieger.jean@laposte.net

R.P.-Y. Chiang and S.-C.J. Kang (eds.), *Introduction to Modern Sleep Technology*,
Intelligent Systems, Control and Automation: Science and Engineering 64,
DOI 10.1007/978-94-007-5470-6_2, 

French scientist Henri Piéron (1881–1964) with his work entitled "Le problème physiologique du sommeil" published in 1913, is usually regarded as the pioneer of the modern approach to sleep research. Advances in technology, and in particular the development of polysomnography which allowed the recording of physiologic changes during sleep, was the turning point that enabled a better understanding of sleep and sleep disorders.

## 2.1 The First Steps: Recording the Electrical Activity of the Brain

Once upon a time, sleep was thought to be a passive state; in fact, sleep was defined as the absence of waking consciousness. Indeed, sleep was often associated to death. In ancient Greek mythology Nyx, the Goddess of Night, had twin sons called Hypnos (Sleep) and Thanatos (Death). Sometimes small figurines depict them as young babies, each suckling on a breast of mother night. Morpheus, the source of dreams, was the son of Hypnos and hence the nephew of Death. This idea that sleep is not an active state runs through most of the history, and it wasn't until the middle of the twentieth century that scientists examined sleep from a physiological perspective.

Previous to this, at the end of the nineteenth century, the Spanish anatomist and neurohistologist Santiago Ramon y Cajal (1852–1934) revolutionized the understanding of the form and nature of cell populations of the nervous system. He demonstrated that the nervous system was composed by independent cells that do not anastomose, but make contact with others at specific points in a highly intricate network. He showed that nervous impulses were transmitted from the cell body out to the axon, and that the axon conducts away from the cell body. Some of the credit for these discoveries belongs to Camillo Golgi (1844–1926), an Italian anatomist and histologist, whose silver stain Cajal modified, and with whom he shared the Nobel Prize in 1906. This work was the basis of our understanding of the functioning of the brain.

A capital contribution to this understanding, and to the development of sleep medicine, was the discovery of the electrical activity of the brain. Luigi (or Aloysio) Galvani (1737–1798) had discovered (working on frogs), at the end of the eighteenth century, that nerve cells of animals produce electricity. Emil DuBois-Reymond (1818–1896), who is considered to be the father of modern electrophysiology, demonstrated the polarized state of nerves and muscle fibers, and showed that the peripheral passage of a nerve impulse was accomplished by an electrical discharge. Hermann Ludwig Ferdinand von Helmholtz (1821–1894) also made significant contributions to the idea that nerve cells use their electrical capabilities for signaling information to one another.

It was finally the Scottish physiologist Richard Caton (1842–1926) who first reported in 1874 the description of the electrical potential changes in the brain

of rabbits and monkeys [9, 13]. He demonstrated that "feeble currents of varying direction" could be recorded from the exposed brain surface of every animal he studied. He conjectured that the activity he observed was related to brain activity, but his work was not recognized until Berger referred to it in his seminal paper in 1929 [4]. Johannes (Hans) Berger (1873–1941) was a psychiatrist from Jena, Germany, and he was the first to record, from the scalp, cortical electrical activity in humans in 1924. He clearly identified the waking alpha rhythm, and observed that if a subject fell asleep, the rhythm disappeared and electrical activity was of very low amplitude or sparse during sleep. Thus, the electroencephalogram (EEG) was born. This discovery constitutes the most critical turning point in sleep research: for the first time, the presence of sleep could be conclusively established without disturbing the sleeper, granted scientists a window into the brain's activity, and the possibility to measure it quantitatively. Lord Edgar Douglas Adrian (1889–1977) was the first scientist to acknowledge and understand the significance of Berger's EEG work, which had been ridiculed as artifact by some.

## 2.2 Sleep Wave Patterns and All-Night Continuous Recordings

All the major elements of sleep wave patterns were shortly thereafter described in a series of experiences conducted by Alfred Lee Loomis (1887–1975) together with Princeton biology professor, E. Newton Harvey, and a local resident, Garret Hobart III, first in a private laboratory in his mansion in Tuxedo Park, NY, and thereafter at Harvard University, where they were joined by Hallowell and Pauline Davis, a husband and wife team of EEG pioneers from Harvard Medical School [10]. In a series of papers published between 1935 and 1939 [11, 12, 30–32] they were the first to describe the characteristic features that now comprise non-REM sleep. They recorded overnight and day sleep, and characterized sleep into five stages (A, B, C, D and E), listed in order of appearance and in order of resistance to change by external disturbances. These studies were completed by others conducted by Blake, Gerard and Kleitman, at the University of Chicago [5, 6]. They further studied sleep depth, attempting to disturb sleep at each stage and measuring the amount of a stimulus that was required to elicit a response.

These experiments began to improve the methods through which sleep was studied. EEG recording evolved, using amplifiers and high and low pass filters. Experimenters found that certain EEG waveforms were best recorded from specific regions of the brain. As a result, certain channels of the EEG gained importance in the recording of sleep. In addition to EEG, sleep researchers experimented with channels that recorded other physiological parameters, such as heart rate and respiration [13].

Nathaniel Kleitman (1895–1999) was the author of the seminal 1939 book Sleep and Wakefulness, and is recognized as the father of American sleep research.

Kleitman was born in Russia and immigrated to the US in 1915. He earned his doctoral degree in physiology and became professor at the University of Chicago, where he set up a laboratory to study sleep in the early 1920s. He was the first to devote the bulk of his entire professional life to the study of sleep, and his laboratory was the first to be permanently devoted to the study of sleep. Next to his office in the physiology building was an old two-room chemistry lab with a door between the rooms. He set up a cot in the room where volunteers would sleep, and left the other room for the observer [14]. He designed a means of measuring movements during sleep and used this technique during experimental sleep recordings [6].

However, the technology was still too primitive and difficult to use. The very first electrodes were small pins that were stuck into the scalps of stoical volunteers. Only a limited number of channels were available for electrode sites, the amplifiers filled an entire room and the recording system used ink pens and required careful calibration before each study. Furthermore, the studies generated large amounts of paper which were difficult to manage. World War II interrupted most research, but was followed by a rapid improvement in technology because of wartime advances in electronics.

The discovery of rapid eye movement (REM) sleep is one of the major advances in the field of sleep research. In the earlier 1950s, Eugene Aserinsky was a graduate student in physiology in the Chicago University sleep laboratory. Kleitman had given him the assignment of watching people's eye movement as they slept. He started observing infants in their cribs in their homes during daytime, and thereafter adults during the night. Nighttime observations were hard work, and watching for eye movements through the eyelids was a tedious task, so they came up with an easier method of recording eye movements, using electrodes placed on the skin next to the eyeballs (the electrooculogram, EOG). The EOG was a means to conveniently and quantitatively measuring eye movements. When used in conjunction to EEG and body movement channels, EOG extended the ability to evaluate the physiology of sleep. Using this system, they were the first to describe the "rapid eye movement" (REM) periods, different from the slow eye movements at the onset of sleep. Additionally, they noted that respiration and heart rate increased during periods of REM. In addition, awakenings when rapid eye movements were present were often associated with rich dream recall. A correlation between REM sleep and dreaming was hypothesized. In fact then, REM sleep, one of the landmark findings in the sleep field, was discovered essentially by accident in 1952. The seminal Aserinski and Kleitman paper was published in 1953[2].

It is important to note, that at the time, to make the job easier and to save paper, the recordings were made for short periods of time, turning on and off regularly, and somewhat randomly, the recording system during the night. In fact, there was no clear reason at the time to record continuously, and in addition it allowed the observer to take a nap between sampling episodes.

In 1952, William Charles Dement (born 1928), at that moment a young medical student, joined Professor Kleitman's group. One of his first assignments was to awaken people during the night and ask them if they remembered dreaming. Motivated by the desire to expand and quantify the description of rapid eye

movements and its relationship with dream activity, Dement made all-night, continuous recordings (EEG, EOG and movement channels) during sleep. It became possible to describe and to quantify the overall patterns of sleep through the night. The cyclical variations of EEG and EOG patterns during sleep were described, and so the different stages of sleep. They proposed a classification of sleep stages: four stages of non-REM (1, 2, 3, and 4) and REM sleep. This can be regarded as the point at which the study of sleep became a true scientific field, as it was the beginning of studying sleep as a whole. This understanding of the electrophysiological substrate of human sleep has been the basis of the development of sleep science. In the 1950s, studies of sleep were always conducted on male volunteers. William C Dement reports, in his book *The Promise of Sleep* [14] that when he proposed to Professor Kleitman to test a woman for REM sleep, he was absolutely opposed. It was only after Dement married that he was allowed to record the sleep of a woman: his own wife. William C. Dement is a pioneering sleep researcher and founder of the Sleep Research Center, the world's first sleep disorders clinical unit, at Stanford University, in 1964. The first patients seen at the newly opened sleep clinic were insomniacs and narcoleptics. Narcolepsy was by that time fully characterized as an interesting and disabling clinical syndrome, requiring sleep recordings for diagnosis. In 1975 he launched the American Sleep Disorders Association, now known as the American Academy of Sleep Medicine (AASM).

The work of Michel Valentin Marcel Jouvet (born 1925) was also pivotal to the detailed early description of the physiological characteristics of REM sleep. In 1959, Michel Jouvet conducted several experiments on cats regarding muscle atonia during REM sleep. Jouvet demonstrated that the generation of REM sleep depends on an intact pontine tegmentum and that REM atonia is due to an inhibition of motor centers in the medulla oblongata. Cats with lesions around the locus coeruleus have less restricted muscle movement during REM sleep, and show a variety of complex behaviors including motor patterns suggesting that they are dreaming of attack, defense and exploration. He pointed out the absence of muscle potentials during the REM periods in cats [24, 25]. This work led to Michel Jouvet's identification of REM sleep as an independent state of alertness, which he called "paradoxical sleep." Jouvet's work put the emphasis on the importance of recording EMG activity to be able to identify REM sleep. With this addition, the basics of polysomnography (PSG), namely EEG + EOG + EMG of postural muscles were defined.

By 1960 it was accepted that there are two fundamentally different kinds of sleep: REM sleep and non-REM sleep, and by that time it was possible to discriminate them by recording the EEG, the EOG and the EMG.

After Dement and Kleitman's article was published, sleep researchers began to use their description of clinical sleep stages. In 1967 a committee of investigators with experience in scoring sleep, led by Allan Rechtschaffen and Anthony Kales, developed a terminology and scoring system to be universally used by sleep specialists [37]. They developed the first consensus-based guidelines for staging and scoring sleep in normal human subjects, commonly called R&K or Rechtschaffen and Kales. The committee recommended using a minimum of one channel of central EEG (either C3 or C4 to the opposite ear or mastoid), chin EMG, and two channels

of EOG (electrodes placed below and lateral to one eye and above and lateral to the other eye, both referenced to the same ear or mastoid). They recommended an epoch-by-epoch approach to scoring, using epochs of 20 or 30 s. Sleep was scored in five different stages: stages 1, 2, 3, 4 and REM. Recording 1 EEG, 2 EOG and 1 EMG (four channels in total) allowed for recording two subjects simultaneously, since the paper then in use was designed to record 8 channels.

However, the limitations of the R & K system became evident with time, in particular with the emergence of sleep disorders medicine [22]. The rules of R&K were clearly designed for normal, usual sleep patterns, not for abnormal or deviant normal electrophysiological patterns. In addition, the R&K system was designed for paper recordings including specifications for filters, gains, paper speed, pen deflection, number of channels, etc., and most of the requirements and guidelines became obsolete with the use of modern digital equipment. From the EEG information, only one derivation was taken into account. The amplitude criteria for the scoring of slow wave were also criticized, as during normal aging the amplitude of the EEG decreases. The NREM stages 2, 3 and 4 were separated by the percentages of time (<20, 20–50 and >50%, respectively) occupied by delta waves, with no clear scientific basis for appointing these values. Nevertheless, the R&K was used from 1968 to 2007, when the *The AASM Manual for the Scoring of Sleep and Associated Events* was published by the American Academy of Sleep Medicine (AASM) [23]. It revised R & K sleep staging and addressed digital methodology, as well as the scoring of arousals, respiratory events, sleeps related movement disorders, and cardiac abnormalities, with consideration of pediatric and geriatric age groups. Thus, for example, according to the AASM Manual, a minimum of three EEG derivations are recommended in order to sample activity from the frontal, central and occipital regions. Slow wave sleep is represented by stage N3 and replaces the R&K nomenclature of stage 3 and stage 4 sleep.

## 2.3 Recording Pathological Sleep

The classic all-night sleep recording could yield a great deal of information concerning sleep duration and characteristics of sleep, in particular in insomniacs and narcoleptic patients. But the extension of polysomnography, with the inclusion of additional sources of information and its imposition as the gold standard tool for the study of sleep and its disorders was not an easy road. Most likely, the first reason was the completely unprecedented nature of an all-night diagnostic test. In addition, it was an expensive, time-consuming and labor-intensive process, which required the conjunction of specialized clinicians and skilled technicians. Another factor to be considered was the reluctance of clinical professionals to work at night, and the fact that most clinical practitioners were completely unaware of the existence of sleep disorders. Sleep medicine as a field was not recognized in the medical community, and the investigations were not reimbursed by health care insurance.

However, in the 1960–1970s a new sleep disorder reared his head, and inspired the evolution of polysomnography. In 1956 Burwell and coworkers published their description of the obesity-hypoventilation syndrome, also known as Pickwickian syndrome, based on the similarity to a character in Charles Dickens' The Posthumous Papers of the Pickwick Club [7]. At the time, sleepiness was thought to be the result of hypercapnia, due to alveolar hypoventilation. However in Europe, a group of researchers became conscious of respiratory abnormalities during sleep in these patients. In fact, the first recordings in sleeping Pickwickian patients, as reported by Peretz Lavie [29], were conducted in 1959 by Werner Gerardy and colleagues at the Ludolf Krehl Klinik of Heidelberg University Hospital, who recorded breathing and pulse rate simultaneously to the EEG [19]. It was the first report in the medical literature on apnoeic events in Pickwickian patients. Two years later, Drachman and Gumnit of the National Institutes of Health, at Bethesda, published an article entitled "Periodic Alteration of Consciousness in the "Pickwickian" Syndrome" in Archives of Neurology [16]. Like Gerardy and his colleagues, Drachman and Gumnit made the recordings during the day. They observed that the moment the patient's EEG showed signs of sleep, his breathing ceased and arterial oxygen saturation level dropped to a minimum of almost 50%. Despite this, none of them connected the sleep disorder with daytime sleepiness.

By that time, Kuhlo, Director of the EEG laboratory at Freiburg University, had a great interest in EEG changes that accompany the process of falling asleep and his predecessor, Richard Jung, had a great interest in the Pickwickian syndrome. They recorded EEG, chest movements with an inflatable belt, carbon dioxide content of expired air, and heart rate of these patients, and correctly concluded that excessive daytime sleepiness in Pickwickian patients was related to their sleep fragmentation, and not due to carbon dioxide poisoning [26].

Gastaut, who headed the Neurobiological Research Unit in Marseille, and his former student, Elio Lugaresi from Bologna, attended the conference where Kuhlo presented their findings. After the meeting, Gastaut assigned two of his younger colleagues, Duron and Tassinari, to monitor Pickwickian patients' sleep [29]. Rather than testing the carbon dioxide content of expired air, they used measurements of mouth and nostril airflow in addition to chest movements, and demonstrated that the reason for the apnoeic events during sleep was the blockage of the upper airways during sleep, in spite of continuous respiratory effort [17, 18]. Repetitive episodes of upper-airway obstruction were terminated by briefs arousals, which in turn fragmented sleep. They confirmed that sleep fragmentation was responsible for the excessive daytime somnolence presented by these patients.

Elio Lugaresi and Giorgio Coccagna from Bologna, also recognized the importance of Kuhlo's observations [29]. The Bologna group's findings in Pickwickian patients supported those of Gastaut et al. and documented three types of apnoea: obstructive, central, and mixed [34]. Lugaresi was the head of the Neurology Department in Bologna, where he also made the first sleep recordings in patients with "restless leg syndrome" [33]. When patients with RLS underwent sleep recordings, they demonstrated periodic involuntary leg movements. EEG showed that they were not a form of epilepsy.

These findings stimulated considerable research in the area of sleep and breathing. Thereafter, neurologists Daniel Kurtz and Jean Krieger of Strasbourg introduced the notion of hypopnoea, or partial apnoea, which like apneas, end with a brief awakening and a slight drop in oxygen saturation level [27]. French neurologist and psychiatrist Christian Guilleminault also played a central role in the early discovery of obstructive sleep apnea. In January 1972 he joined the Standford Sleep Center, and working in collaboration with Dr. William C. Dement, Guilleminault established the Apnea/Hypopnea Index (AHI) which is still in use today to diagnose sleep apnea and measure its degree of severity [20]. It was in this paper that the term "Sleep Apnea Syndrome" was first used, and a definition for the syndrome based on polysomnographic findings was provided. Guilleminault later also described Upper Airway Resistance Syndrome (UARS) as a sleep disorder characterized by increased airway resistance to breathing during sleep. The seminal article on UARS is "A cause of excessive daytime sleepiness: The upper airway resistance syndrome", which Guilleminault co-published in the journal *Chest* [21]. To confirm the diagnosis, it was necessary to use a probe to measure esophageal pressure (Pes), to demonstrate a progressive elevation of esophageal pressure swings which terminated with an arousal, in the absence of apnoeas or hypopneas.

The discovery of sleep breathing disorders imposed the use of respiratory and cardiac sensors in sleep studies. Electromyogram (EMG) of the muscle tibialis was added to monitor periodic legs movements.

Thus the need to identify abnormal events during sleep necessitated the inclusion of more sensors in addition to the basic EEG, EOG and EMG recordings required to identify sleep stages. The number and type of additional sensors of course depends on the nature of the suspected disorder for which a given patient is investigated. However, because of the high prevalence of respiratory disorders and periodic movements during sleep, respiratory and leg movement sensors became a routine part of the all-night diagnostic test which was named polysomnography in 1974 by Dr Jerome Holland, a member of the Standford group [3]. The name is derived from Greek and Latin roots: the Greek 'poly' for multi-channel (many), the Latin 'somnus' (sleep), and the Greek 'graphein' (to write). At the initial stage, "poly" was only two, but as we just have described, with the rapid improvement of technology, the number of sources of information soon increased.

In 1975 Mary Carskadon, now Professor in the Department of Psychiatry and Human Behavior at the Warren Alpert Medical School of Brown University, joined the Standford Sleep Center. Along with Dement, she developed the Multiple Sleep Latency Test (MSLT) used to clinically determine sleepiness in sleep disordered patients, particularly by measuring daytime sleep onset latency [8]. Conceiving and developing an objective measure of sleepiness is considered one of the most important advances in sleep medicine [14]. The test consists of four or five 20 min nap opportunities that are scheduled about 2-h apart. The test is often done following an overnight sleep study. During the test, EEG, muscle activity and eye movements are monitored and recorded. These measure the time it takes from the start of a daytime nap period to the first signs of sleep; the sleep latency. With time, other methods have been developed to measure sleepiness "objectively" such as the Maintenance Wakefulness Test (MWT) [15].

Many physiological variables can be recorded during a polysomnography, such as end-tidal or transcutaneous carbon dioxide, temperature (via a rectal probe), additional EMG channels, additional EEG channels (when epilepsy is suspected), CPAP pressure and so on; the choice of the appropriate variables to be monitored depends on the nature of the disorder for which the patient is being investigated.

Each one of the techniques used to record these parameters has undergone its own evolution. This is the example of oximetry [35]. The first oximeters were developed in the early 1940s by a British researcher, Millikan, who developed an ear oxygen meter for aviation, for which he coined the word "oximeter". The system went through many modifications during the 1940s and 1950s, and was eventually manufactured by the Waters Company. In 1964, a San Francisco surgeon developed a self-calibrating, 8-wavelength oximeter that was marketed by Hewlett Packard in the 1970s. However, it was large, cumbersome, expensive, and required the heating of the ear lobe to which it was applied, which added to the discomfort. In the early 1970s, Takuo Aoyagi, a Japanese bioengineer, found that it was possible to use the pulsating changes in the light transmission through the ear to measure arterial oxygen saturation. He then went on to develop a pulse oximeter and applied for a Japanese patent. At the same time, another Japanese researcher from Minolta was working on the same concept and applied for a patent a month later. This patent was denied in Japan but approved in the U.S. In the late 1970s, the Biox Corporation in U.S. made significant advances in pulse oximetry, 2-wavelength measurements. They first introduced the use of Light Emitting Diodes (LEDs) for the red and infrared light sources. It allowed continuous, real time, noninvasive oxygen saturation readings. Ohmeda Corporation purchased Biox, and in the 1980s, along with Nellcor and Novametrix, continued to make significant advances in size and cost reductions. Oximeters became smaller in size, easier to apply, and less expensive. In 1995, fingertip oximeters, which are small enough to put a finger in, first appeared on the market. All these improvements in oximeter techniques were progressively introduced to polysomnographic recordings.

Major improvements have been also made in the methods of recording airflow. The reference standard measurement of airflow is the pneumotachometer. It allows continuous monitoring of total oronasal airflow, which in most circumstances requires a snug-fitting face mask. It is a relatively bulky and uncomfortable system, so historically other methods for recording airflow have been employed [1]. An easier to use method is the detection of airflow by thermal sensors (thermocouples and thermistors) which have been traditionally used to determine airflow during polysomnographic studies. A thermistor is a type of resistor whose resistance varies with temperature, but it provides only qualitative information that is not well correlated with breathing amplitude. Therefore, a relative reduction in amplitude (e.g. >50%) of this signal cannot be used to reliably indicate the presence or absence of a hypopnea. The signals from the thermal sensors have been shown to be non-linearly related to actual airflow, while generally resulting in an overestimation of ventilation. Nasal prong pressure measurements are becoming increasingly popular for quantifying respiratory events during sleep. Detection of fluctuation in nasal pressure during inspiration and expiration reflects changes in inspiratory and

expiratory airflow. Studies have shown that nasal pressure is much more sensitive than thermal sensors for detecting hypopneas and much more comfortable for the patient than pneumotachometers. Other methods to record airflow during sleep include: Dual channel respiratory inductance plethysmography (RIP, the sum of chest and abdominal signals), single channel RIP, piezo sensors, strain gauges, thoracic impedance and expired carbon dioxide.

With regards to the measurement of respiratory effort, esophageal pressure remains the reference standard. It discriminates between obstructive and central hypopneas, and is the gold standard for the diagnosis of upper airway resistance syndrome. Nonetheless, it is a relatively invasive technique which is not always well tolerated during a full-night polysomnography. Detection of flow limitation by nasal pressure monitoring is possible, since the shape of a continuous recording of inspiratory and expiratory pressure can detect flow limitations with either a full face mask or a nasal pressure cannula. However, if only nasal pressure cannulae are used, the technique may lack sensitivity if the patient employs predominantly mouth breathing. Other techniques have been developed to record respiratory effort, such as supraglottic pressure and diaphragmatic surface EMG, but there are no data on accuracy, reliability, or correlation with long term outcome in relation to these techniques.

In many of these technique improvements, in particular in recent years, the effort of commercial companies to improve the performances of polysomnographers, and to develop user-friendly and less expensive systems is obvious. In many cases, market forces dictate which techniques survive and which do not.

## 2.4 Polysomnography Today

With the advent of the laboratory computer capable of signal processing, it is possible to acquire, manipulate and store multiple physiologic data during sleep. Today, computerized recording and storage systems have all but replaced the paper-based analog polysomnograph recordings. This has solved the storage problems related to the production of massive quantities of paper, and has allowed the possibility of recording multiple channels. From a data processing standpoint, five basic and distinct processes can be defined [36]:

1. data acquisition (recording)
2. data display (viewing)
3. data manipulation (scoring and editing)
4. data reduction (parameterization for reporting)
5. data filing (storage)

Computerized data acquisition and storage permits monitoring numerous functions during a polysomnography, typically including: EEG, EOG, mental-submental EMG, muscle activity (typically, tibialis anterior EMG, to detect leg movements),

electrocardiogram (ECG), airflow, respiratory effort, sound (to record snoring), peripheral pulse oximetry, body position and continuous video recording.

Typically, the sleep laboratory is located in the hospital, and for the standard test, the patient comes in the early evening, and over the next 1–2 h is introduced to the setting, whilst electrodes and other monitoring devices are applied so that the multiple channels of data can be recorded when he/she falls asleep. A sleep technician should always be in attendance and is responsible for attaching the electrodes to the patient and monitoring the patient during the study. During the study, the technician observes sleep activity by watching the video monitor and the computer screen that displays all the data. In most labs, the test is completed and the patient is discharged home by 7 a.m. unless a MSLT or a MWT is to be done during the day to test for excessive daytime sleepiness. After the test is completed, a 'scorer' analyzes the data by reviewing the study in 30 s 'epochs'. Ways to automate sleep scoring have been described, but they cannot replace the visual scoring [36]. Once scored, the test recording and the scoring data are sent to the sleep medicine physician for interpretation. The American Academy of Sleep Medicine has published practice parameters for polysomnography, regarding the indications in the diagnosis of sleep disorders [28].

In addition to full-night polysomnography, daytime nap studies and split-night studies have been developed to reduce costs, and can provide substantial information. Typically, during a split-night recording the first part of the night is devoted to determine the presence and evaluate the severity of a sleep breathing disorder. During the second part of the night, a CPAP titration study is performed to determine the correct amount of pressure, the right mask size, and also to make sure the patient is tolerant to this therapy.

Portable systems have also been developed to record at home a wide range of parameters, similar to those used in laboratories. The diagnostic value of portable devices is reduced by the inability to make behavioral observations, standardize recording conditions, address technical problems, or make interventions during the night.

## 2.5 Summary

This brief historical review chronicles the parallel evolution of sleep research and polysomnography. The rate of progress has been incredible from the first EEG recordings to computerized multichannel polysomnographs. From the 1930s through the 1950s, scientists worked to reveal the properties of normal sleep. Concomitantly, the technology of recording sleep evolved. By the end of the 1950s, experimenters were performing full-night recordings of sleep. Beginning in the 1960s and going forward, sleep researchers began to apply new technology to study sleep pathology. The field of clinical sleep medicine began to develop beside a growing discipline of sleep research. The 1980s and 1990s saw the expansion of

sleep medicine and the acceptance of polysomnography as an important diagnostic tool. The rapid advancement of sleep research and the growing clinical knowledge of sleep disorders led to an increasing demand for polysomnographies, and centers devoted to the diagnosis and treatment of disorders of sleep have multiplied in recent years. The swift development of polysomnographs was possible thanks to the development of computer polysomnographs. Computerized polysomnography involves recording, analyzing, displaying, scoring, tabulating, distilling, and storing sleep studies. The greatest challenge for the future will likely be the cost-effective expansion of sleep medicine, so that its benefits could be profitable to the entire population. The technology must provide us with better and comprehensive systems to respond to this demand, and provide solutions to the sleep problems faced by individuals and society.

## References

1. American Academy of Sleep Medicine Task Force (1999) Sleep-related breathing disorders in adults: recommendations for syndrome definition and measurement techniques in clinical research. Sleep 22(5):667–689
2. Aserinsky E, Kleitman N (1953) Regularly occurring periods of eye motility, and concomitant phenomena, during sleep. Science 118(3062):273–274
3. Atkinson JW (ed) (2007) The evolution of polysomnographic technology. Lippincott, Williams & Wilkins, Philadelphia
4. Berger J (1929) Uber das Elektrenkephalogramm des Menchen. Arch Psychiatr Nervenkr 87:527–570
5. Blake H, Gerard R (1937) Brain potentials during sleep. Am J Physiol 119:692–703
6. Blake H, Gerard R, Kleitman N (1939) Factors influencing brain potentials during sleep. J Neurophysiol 2:48–60
7. Burwell CS, Robin ED, Whaley RD, Bickelmann AG (1956) Extreme obesity with alveolar hypoventilation: a Pickwickian syndrome. Am J Med 21:811–818
8. Carskadon MA, Dement WC (1977) Sleep tendency: an objective measure of sleep loss. Sleep Res 6:200
9. Caton R (1875) The electric currents of the brain. Br Med J 2:278
10. Colrain IM (2005) The K-complex: a 7-decade history. Sleep 28(2):255–273
11. Davis H, Davis P, Loomis AL, Harvey EN, Hobart G (1937) Changes in human brain potentials during the onset of sleep. Science 86:448–450
12. Davis H, Davis P, Loomis AL, Harvey EN, Hobart G (1939) Electrical reactions of the human brain to auditory stimulation during sleep. J Neurophysiol Clin 1939:500–514
13. Deak M, Epstein LJ (2009) The history of polysomnography. Sleep Med Clin 4(3):313–321
14. Dement WC (ed) (1999) The promise of sleep. Dell Publishing, New York
15. Doghramji K, Mitler MM, Sangal RB, Shapiro C, Taylor S, Walsleben J, Youakim JM (1997) A normative study of the maintenance of wakefulness test (MWT). Electroencephalogr Clin Neurophysiol 103(5):554–562. doi:S0013469497000102 [pii]
16. Drachman DB, Gumnit RJ (1962) Periodic alteration of consciousness in the “pickwickian” syndrome. Arch Neurol 6:471–477
17. Gastaut H, Tassinari CA, Duron B (1965) Polygraphic study of diurnal and nocturnal (hypnic and respiratory) episodal manifestations of Pickwick syndrome. Rev Neurol (Paris) 112(6):568–579

18. Gastaut H, Tassinari CA, Duron B (1966) Polygraphic study of the episodic diurnal and nocturnal (hypnic and respiratory) manifestations of the Pickwick syndrome. Brain Res 1(2):167–186. doi:0006-8993(66)90117-X [pii]
19. Gerardy W, Herberg D, Kuhn HM (1960) Comparative studies on pulmonary function and the electroancephalogram in 2 patients with Pickwick's syndrome. Z Klin Med 156:362–380
20. Guilleminault C, Dement WC (1977) 235 cases of excessive daytime sleepiness. Diagnosis and tentative classification. J Neurol Sci 31(1):13–27
21. Guilleminault C, Stoohs R, Clerk A, Cetel M, Maistros P (1993) A cause of excessive daytime sleepiness. The upper airway resistance syndrome. Chest 104(3):781–787
22. Himanen SL, Hasan J (2000) Limitations of Rechtschaffen and Kales. Sleep Med Rev 4(2):149–167
23. Iber C, Ancoli-Israel S, Chesson A, Quan SF, for the American Academy of Sleep Medicine (eds) (2007) The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications. American Academy of Sleep Medicine, Westchester
24. Jouvet M, Michel F, Courjon J (1959) On a stage of rapid cerebral electrical activity in the course of physiological sleep. C R Seances Soc Biol Fil 153:1024–1028
25. Jouvet M, Mounier D (1960) Effect of lesions of the pontile reticular formation on sleep in the cat. C R Seances Soc Biol Fil 154:2301–2305
26. Jung R, Kuhlo W (eds) (1965) Neurophysiological studies of abnormal night sleep and the Pickwickian syndrome. Elsevier, Amsterdam
27. Kurtz D, Krieger J, Lonsdorfer J (1976) Hypo-apneic sequences in pickwickian subjects. Apneic grouping and trains on apnea. Rev Electroencephalogr Neurophysiol Clin 6(1):62–69
28. Kushida CA, Littner MR, Morgenthaler T, Alessi CA, Bailey D, Coleman J Jr, Wise M (2005) Practice parameters for the indications for polysomnography and related procedures: an update for 2005. Sleep 28(4):499–521
29. Lavie P (2008) Who was the first to use the term Pickwickian in connection with sleepy patients? History of sleep apnoea syndrome. Sleep Med Rev 12(1):5–17
30. Loomis AL, Harvey E, Hobart G (1935) Further observations on the potential rhythms of the cerebral cortex during sleep. Science 82:198–200
31. Loomis AL, Harvey E, Hobart G (1935) Potential rhythms of the cerebral cortex during sleep. Science 81:597–598
32. Loomis AL, Harvey E, Hobart G (1938) Distribution of disturbance patterns in the human electroencephalogram, with special reference to sleep. J Neurophysiol 13(Suppl):231–256
33. Lugaresi E, Coccagna G, Tassinari CA, Ambrosetto C (1965) Polygraphic data on motor phenomena in the restless legs syndrome. Riv Neurol 35(6):550–561
34. Lugaresi E, Coccagna G, Petrella A, Berti Ceroni G, Pazzaglia P (1968) The disorder of sleep and respiration in the Pickwick syndrome. Sist Nerv 20(1):38–50
35. Middleton PM, Henry JA (2000) Pulse oximetry: evolution and directions. Int J Clin Pract 54(7):438–444
36. Penzel T, Hirshkowitz M, Harsh J, Chervin RD, Butkov N, Kryger M, Chesson AL Jr (2007) Digital analysis and technical specifications. J Clin Sleep Med 3(2):109–120
37. Rechtschaffen A, Kales A (eds) (1968) A manual of standardized terminology, techniques, and scoring system for sleep stages of human subjects. Public Health Service, U.S. Government Printing Service, Washington, DC

http://www.springer.com/978-94-007-5469-0

Introduction to Modern Sleep Technology
Chiang, R.P.-Y.; Kang, S.-C. (Eds.)
2012, XXIV, 296 p., Hardcover
ISBN: 978-94-007-5469-0