Chapter 4
ECG Pilot Studies

Abstract The use of wireless ECG body sensors in two pilot studies is presented. The first study, running at the Department of Cardiovascular Surgery of the University Medical Centre Ljubljana, is focused on the investigation of postoperative atrial fibrillation. The patients are monitored with wireless ECG body sensors one day before and five days after the surgery. The second study has been established at the primary care level in the Community Health Centre Ljubljana, with the intention to establish heart rhythm screening. As both studies are still in progress, we present just their setup and some interesting findings that emerged in their starting phase. Based on evidences from long-term ECG measurements, we identify several still open ECG research questions that could utilize the vast amount of long ECG recordings obtained from the pilot studies.

4.1 Motivation

An unobtrusive and lightweight ECG body sensor can be used for long monitoring of the heart's activity in many different situations. The unobtrusiveness is the key for long-term use. In medicine, the term patient means a person under health care, however, at the same time, a patient also means "someone who suffers". With an appropriately designed system, the measuring procedure should not impose additional suffering. The wireless ECG sensor used in the two pilot systems approaches this goal in the sense that "a patient can be less patient".

The long-lasting collaboration between the Jožef Stefan Institute and the University Medical Centre Ljubljana (UMCL) in the research field of electrocardiology has resulted in many publications [1–10]. Among them, several are on the topic of cardiac rhythms before and after cardiac surgery. As postoperative atrial fibrillation (AF) is a common complication after cardiac surgery, the Department of Cardiovascular Surgery at the UMCL decided to conduct a prospective biomedical research study about it. The study was approved by the National Medical Ethics Committee of the Republic of Slovenia in 2015.

On the other hand, there has not been a previous collaboration between the Jožef Stefan Institute and the Community Health Centre Ljubljana (CHCL) in the field

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of cardiology. The possibility for collaboration emerged in the last years, when we realized that the use of smartphones (or tablets) can bring the ECG monitoring to everyone who needs it in a simple, safe and affordable way. The initial study [11] started with 13 volunteers for validation of the measurement protocol that was subsequently supplemented. The final goal of the study is to find out if several days of ECG monitoring at home, by using an unobtrusive ECG body sensor, can lead to an earlier evidence-based decision about anamnestic suspicion for cardiac rhythm disturbances.

The research of cardiac electrophysiology could benefit from the vast amount of ECG data that will emerge from broad use of ECG sensors. Some of the interesting research questions on ECG are: what is the real origin of the T wave; what is the origin of the U wave; is there only one sinus node or are there active regions in the atria that perform pacemaking function; what is behind the sick sinus syndrome; can we predict the onset of AF. We tangle some of them in the last section, where we present a few examples from the first steps of the pilot studies.

4.2 Atrial Fibrillation After Cardiac Surgery—A Study at the University Medical Centre Ljubljana

Postoperative AF (POAF) is a complication that often emerges after cardiac surgery. It can result in many health-related complications and in the need for increased healthcare resources. The findings in prediction and prevention of POAF in the last years are not enough to resolve the problem and there is still some uncertainty about the risk stratification and the management of POAF. As reported recently [12], the Department of Cardiovascular Surgery at the UMCL extended a previous study [5, 7] and introduced a new clinical study about the mechanisms of AF, to determine the dynamics of the heart rhythm and the electrophysiological properties of the heart after cardiac operation.

The clinical study utilizes wireless ECG monitoring after surgery for the evaluation of malignancies of the rhythm and the estimation of electrophysiological properties. Within the first stage of the study, a tablet showing the current heart rhythm is posted near the patient's bed and the analysis of the measured ECG is done afterward by a trained expert with computer-supported assistance. If the study is able to demonstrate that online monitoring with automatic recognition of certain events is beneficial, the required functionality will be implemented in the monitoring system to provide online analysis. The wireless ECG monitoring starts one day before surgery and lasts until the fifth postoperative day. AF is expected to occur in some patients in this time frame. It is supposed that such long-term monitoring and analysis of the obtained recordings could enable preventive activity before the start of the expected AF. The activity is planned for implementation in the second stage of the study.

4.2.1 Participation in the Study

The candidates for inclusion in the study are patients anticipated for elective cardiac surgery in the sinus rhythm and patients with expected surgical ablation of AF alone or together with other cardiac surgery. Excluded are: patients with a cardiac pacemaker, urgent cardiac surgery or previous open-heart surgery.

4.2.2 Procedures

One day before surgery, 20 min of high-resolution standard 12-lead ECG recording is obtained for short-term heart rate variability analysis and standard ECG analysis. In the same time, a wireless ECG sensor with two electrodes is placed on the patient's chest for obtaining one-day basal ECG status. The ECG sensor is removed during the surgery and placed again after the surgery for five days. The placement of the sensor is critical, because there is a postoperative wound on the chest and the atrial P wave should be clearly visible. The ECG is recorded on a tablet computer near the patient and also shown on the tablet for the medical practitioners. During the 6-day measurements, an irritation on the skin under the electrodes is possible. In such a case, the ECG sensor should be moved to another position on the body. The tablet is connected to the mains adapter all the time, while the ECG sensor has enough autonomy for the whole period of measurement.

After a 6-day period, the ECG recordings are transferred to a secure computer server for further visual inspection by a medical expert. The goal is to identify the AF burden, e.g. the number and the duration of AF periods. This procedure is described in more detail in the next section. It is expected that such long-term ECG measurements, and other data obtained during the study, will help to better understand the evolution of POAF and the re-emerging of AF after the surgical procedure. With better recordings and understanding of AF, there is a possibility of predicting the risk for AF, which could lead us to use preventive strategies in the identified groups.

4.3 Heart Rhythm Screening—A Study at the Community Health Centre Ljubljana

The pilot study was designed recently at the primary care level at the CHCL, which is taking care for more than 440.000 registered patients. We hope that it will trigger a broad penetration of the ICT into the primary care and also improve the integrated health care with evidence-based decisions. The initial phase of the study [11] tests the pilot protocol within fifteen patients and healthy volunteers. The established study protocol was confirmed in November 2016. Two hundred patients are going to be enrolled, divided randomly in two groups: half of them will wear the ECG body sensor (the test group) and the other half will be maintained according to the classic clinical path (the control group). We expect that the CHCL pilot will provide valuable responses from medical practitioners, patients and caregivers, which can lead to further improvement of the global mHealth system.

4.3.1 Participation in the Study

Patients with no previous diagnosis of heart rhythm disturbances and with an anamnestic suspicion for rhythm disturbance not confirmed previously by a standard 12-lead ECG or Holter ECG are invited to participate in the study. The included patients are further divided in two groups: the test group – where the wireless ECG body sensor is used for 2 days, and the control group – where a standard treatment is taken. The randomized classification of patients into groups is performed by a simple procedure: the first patient is in the test group, the second in the control group, the next one in the test group, and so on. All study participants have to sign an informed written consent before their enrolment.

4.3.2 Procedures

For patients in the test group, the procedure is as follows:

(a) During appointment No. 1, the doctor performs clinical examination and fills in a form with patient's data and anamneses.
(b) The patient receives a diary that he/she will be filling in at home for the period until the next appointment.
(c) The next appointment at the doctor is scheduled after 5–10 days (depending on the capability of the simulation center).
(d) The patient is referred to the simulation center where he/she is equipped with an ECG body sensor, a smartphone and instructions for use.
(e) After two days, the patient returns the ECG sensor and the smartphone to the simulation center—the ECG recording from the smartphone storage is transferred to a secure computer server in the CHCL.
(f) Before appointment No. 2, the doctor examines the patient's ECG recording.
(g) During appointment No. 2, the doctor:

- examines the patient's diary,
- takes appropriate measures: observation, introducing drugs, directing the patient to a clinical specialist, further examinations, or prolongation of the ECG sensor measurement,
- fills the form with results of the clinical examination.

(h) If there was a decision for a prolonged ECG sensor measurement, the doctor proceeds as in (b)–(h). At most two prolongations of the ECG measurement are possible.

For patients in the control group, the procedure is the same as above, except that there are no actions in (d), (e), (f) and (h), because these patients do not use an ECG body sensor.

4.3.3 Simulation Center

A patient comes in the simulation center (SIM) of CHCL to get an ECG body sensor, a smartphone and user instructions. First, the whole procedure is explained by a trained medical technician and then the ECG sensor is placed on the patient's chest at the position where all electrocardiographic waves (P, QRS, T) are clearly visible. There are several standardized sensor positions. The medical technician and the patient find an optimal position, most often with the first attempt, or by testing among a few standardized locations that provide an adequate visibility of the P wave, which is essential for the arrhythmia analysis. The location should be comfortable for the patient and result in an adequate quality of the recorded ECG signal. The patient is instructed how to place the sensor at home, in the case of a bad contact between the electrodes and the skin or in the case of an eventual skin irritation from the electrodes, and where to place the smartphone for a minimally interrupted radio connection. Finally, the patient receives simplified written instructions about all the procedures of the study protocol.

During the initial phase of the study, we have found out that many advanced features of the mobile application, e.g. marking events, inserting comments, generating ECG reports, etc., are not applicable for older patients, who are often not accustomed to use smartphones. Also, several participating volunteers were troubled even by watching the ECG signal—they are not familiar to monitor the ECG during daily activities, when the baseline could be extremely unstable and EMG signals are superimposed to the ECG signal. Based on the patient decision, the SIM center personnel either enables or disables the ECG signal visualization during the measurement. After two days, the patient returns the devices and his diary. The ECG data from the smartphone are transferred to the computer server where an authorized doctor can examine the ECG recording.

4.4 Visual Examination of the ECG Recordings

We have established that the most efficient way to examine a long-term ECG recording is to look over a graphic presentation of the recording in the form of an ECG report (for an example, see Fig. 4.1). Each heartbeat is presented as a thin point with

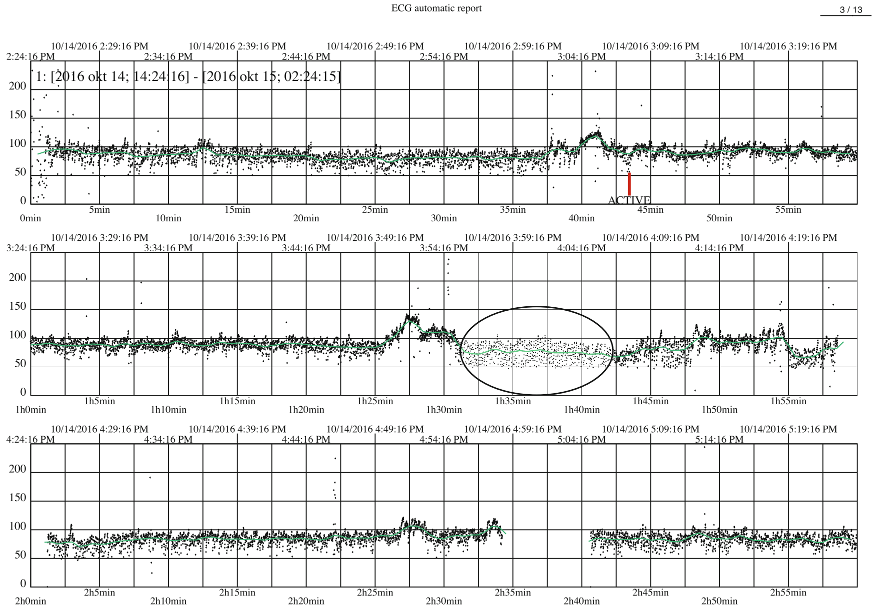

Fig. 4.1 Heart rate shown as a BPM graph obtained from an automatically generated ECG report (3 h of recording are shown in 3 lines). Each point represents a heartbeat at an instantaneous BPM

instantaneous heart rate normalized per minute, defined as $BPM = 60/(RR\ time)$, where RR is the interval between two consecutive R waves. The graphic presentation of the BPM is obtained automatically, by a computer-supported beat detector and a visual report over the whole ECG recording. There are some simple rules that can help in an initial visual examination of the ECG report:

- In sinus rhythm, especially at higher heart rates, the RR time intervals between successive beats have similar length, and consequently also the BPM, which leads to a narrow line of points in the BPM graph.
- At lower heart rates, there is often the respiratory sinus arrhythmia that broadens the BPM line.
- In the case of AF, the BPM line will be normally extremely broadened, because of non-synchronized heart activity.
- Each premature ventricular beat can be detected by a pair of points that stand out from the BPM line, the first being significantly above the BPM line and the second being significantly below the BPM line.

We found out that on one-hour BPM intervals, all common important arrhythmic evens can be identified. With a presentation of one one-hour BPM graph per line, it is possible to perform an initial examination of a long-term recording quite fast, because, e.g., 24-h of ECG fit on four A4 pages of the ECG report. In case of doubts,

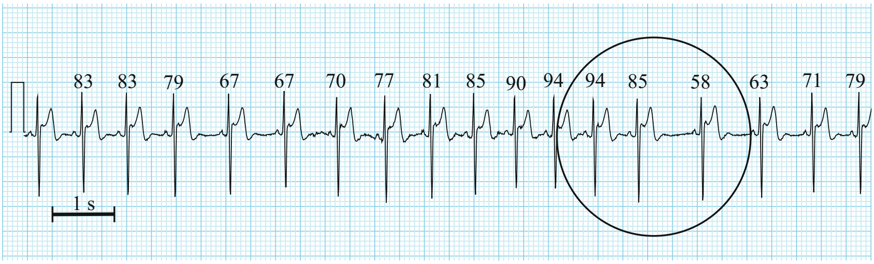

Fig. 4.2 Details from the ECG signal: sinus rhythm, because the P waves are present before each QRS complex, and unusually high HRV. The BPM goes from 94 to 58 in just 2 beats (*encircled*)

we can simply look into the original ECG measurement at that time point to see all the details of the ECG signal.

In Fig. 4.1, an example of an unusually broad BPM line is shown, even at higher heart rates. The ECG signal of about ten minutes from the encircled region, with extremely high HRV, is shown in Fig. 4.2. Visual examination of the region confirms high HRV, but still a sinus rhythm, because the P waves are clearly visible before each QRS complex. The recording is from a young male.

4.5 Long-Term ECG Data and New Knowledge

The sensor ECGs are bipolar measurements that enable a new, narrower look on the heart. In the case of several such sensors, we are able to sample the body potentials on several independent locations, which provides opportunities for new ways of ECG signal interpretation. The vast amount of ECG data that can be expected from a broad use of ECG sensors cannot be practically analyzed by visual inspection. New data analytics of the ECG Bigdata needs to be developed, substantially supported by advanced computer programs based on knowledge management and extraction. Furthermore, two proximal electrodes could provide novel answers to the old questions in electrocardiography.

The genesis of the T wave in ECG is not completely understood and is a subject of controversy. Is the T wave a result of transmural heterogeneity of repolarization or heterogeneity among different parts of the heart (apex to base) or both [13, 14]? Next, the underlying electrophysiological basis of the U wave genesis [15] has not been precisely elucidated. Several hypotheses have been proposed, e.g. delayed repolarization, mechanoelectrical interactions, transmural dispersion of repolarization, etc. The recordings from ECG sensors could contribute to the resolution of these questions.

Another uncertainty arises when we observe the cardiac rhythm. The sinus rhythm, which is the normal one, by definition originates from the sinus node in the atrium. However, in 1988, Boineau et al. demonstrated that a widely distributed atrial pacemaker complex is present in the human heart [16]. There is a question how the physiology of the heart makes these structures functional and alive throughout the life cycle. These structures are often called "ectopic focuses". A question arises: Do these regions serve as a "backup" for the sinus node function or as something else? On the one hand, they could be redundant pacemaker regions, but on the other hand, they could lead to an arrhythmia.

Beside patients with an irregular heart rhythm, other chronic patients, for example, Chronic Obstructive Pulmonary Disease (COPD) patients, are also candidates for the ECG sensor monitoring. According to the World Health Organization (WHO), the COPD is the third most frequent cause of death worldwide [17]. COPD patients are usually outpatients, except in cases of exacerbation (sudden worsening of their health status, which happens in average 1–4 times per year), for which they might be hospitalized. More than 70% of COPD–related healthcare costs are a consequence of emergencies and hospital stays for the treatment of exacerbation [18]. On the other hand, remote monitoring can reduce the frequency and severity of COPD exacerbation symptoms [19], and consequently reduce the costs.

Reports show that the primary cause of death for COPD patients is cardiac failure [20, 21]. Myocardial infarction is the co-morbidity with the greatest potential for treatment and prevention to improve the prognosis of COPD patients [20]. In general, cardiovascular diseases are the most frequent comorbidities with COPD and include the following entities: coronary artery disease, heart failure (about 30% of patients with stable COPD show some degree of heart failure), arrhythmias, and hypertension [22, 23]. It is, therefore, of the highest importance to continuously monitor cardiac electrical activity and issue alarms when dangerous events are detected. Besides, one of the signs of COPD exacerbation is respiratory rate over 25/min [24]. It is, therefore, important to measure also the respiratory rate, which is possible with no extra devices, as explained in Sect. 2.4.

A few indicative examples obtained from long-term ECG measurements are presented in the next chapter. All the cases have been obtained from volunteering users of the Savvy ECG sensor.

4.6 Sensor ECG Examples

4.6.1 Extranodal Pacemakers

An examination of an overnight sensor ECG measurement, reported previously in a paper by Avbelj [25], is presented in the following with more details. From the previous chapters, we know that a sensor ECG recording encompasses a variety of information that can be extracted from the raw sensor ECG signal. The amplitude and the morphology of the ECG waves change according to the change of the ECG sensor position relative to the heart. Using this phenomenon, the respiration rate can be derived from the ECG, as explained in Sect. 2.4. User activities can be evaluated by

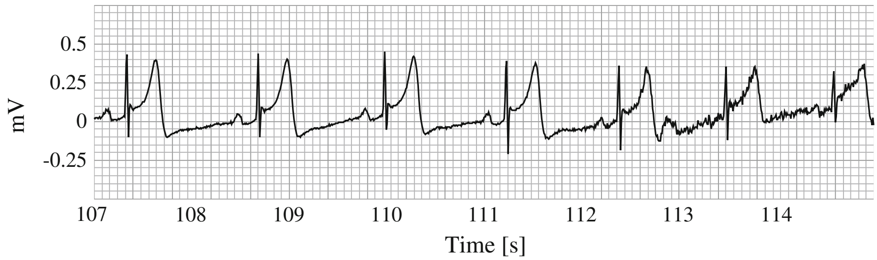

Fig. 4.3 Muscle noise in ECG is used for the detection of an effort to change the body position during the sleep. See the noise starting at the 112th second

an additional 3-D acceleration (gravity) sensor that is able to reliably measure body movements and body position changes. However, the activity can be evaluated also from the ECG signal. For example, the skeletal muscle signals (EMG) superimposed to the ECG signal are normally taken as an unwanted noise, but they can be an indicator of an activity or of an effort to change the position of the body during the sleep (see Fig. 4.3).

Further examination of the same ECG recording revealed unexpected extranodal pacemaker activity, which is usually not recognized as a normal physiological activity of the atrium. In Fig. 4.4, we see several fast changes of the heart rate during the night. The most striking event was observed around 5 AM. The heart rate increased from 48 BPM to 86 BPM in less than 15s, then quickly dropped to 55–58 BPM, and finally dropped abruptly to the value from before the episode, whose duration was 76s. It is not known what was the reason of the heart rate speed-up after the 109th second. Interestingly, the heart rate started to rise a few seconds before the appearance of the muscle noise (at the 112th from Fig. 4.3).

An abrupt change of the morphology of the P wave (compare P waves denoted by signal markers A1 and A2 in Fig. 4.4) occurred during the speed-up of the heart rate. It seems that an alternative pacemaking region starts to lead the heart rate. After the P wave morphology had been changed, it remained the same until the end of the, when the heart rate returned to the previous value. During the slowdown of the heart rate, an abrupt change in the P wave morphology occurred again at the end of the episode (see ECG signal markers B1 and B2). The shown ECG recording evidences a complex behavior of pacemaking structures in the atria. The change in the P wave morphology can be interpreted as a change in the region of the leading pacemaker. As a provocative hypothesis, we could speculate that this episode can be seen as “a training cycle” of a particular pacemaking region, which helps to preserve this region alive and functional.

It is believed that the sinus node is the origin of each heartbeat in normal cases, although there is a growing evidence for the physiological operation of extranodal pacemaker sites, which results from a widely distributed atrial pacemaker complex in the human heart [16]. In a previous study, we documented such a pattern in the process of deceleration of the heart rate during a spontaneous cardioinhibitory syncope [26].

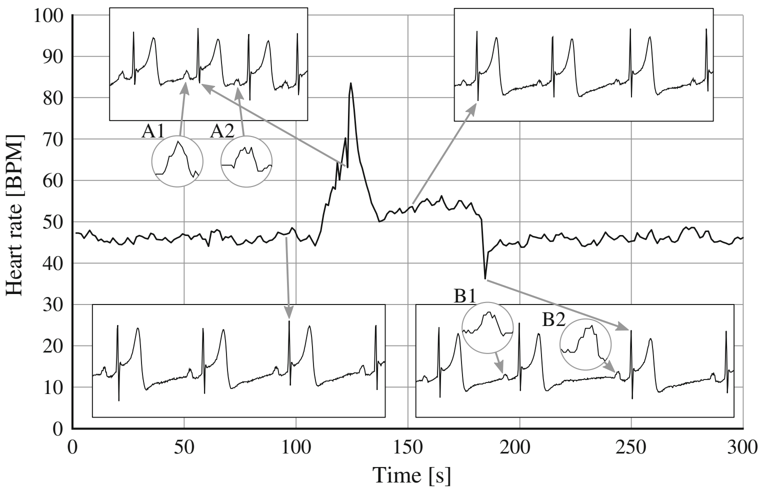

Fig. 4.4 Heart rate in an interval of 5 min around 5 AM. An abrupt change in the heart rate occurred after the 109th second and further a change in the morphology of the P wave can be seen (ECG signal markers *A1* and *A2*). During the slowdown of heart rate, an abrupt change in the morphology of the P wave occurred at the end of the episode (ECG signal markers *B1* and *B2*). This is an indication of a complex behavior of pacemaking structures in the atria

4.6.2 Atrio-Ventricular Block in an Athlete During Sleep

It is well known that the sinus node (SN) and the atrio-ventricular (AV) node are under the control of the sympathetic and parasympathetic (vagal) nervous system. The vagal branch of the system can modulate the time intervals in an ECG on a beat-by-beat basis. Higher vagal input into the SN decreases the frequency of SN depolarization, while higher vagal input into the AV node lengthens the PR interval and could even prevent the conduction of a depolarization wave from atria to ventricles—vagally mediated AV block [27].

In the following, we analyze a 24-h single-channel ECG recording with the electrodes positioned approximately at the positions of V1 and V2 of the standard 12-lead ECG. From the previous chapters, we know that in this case, the ECG represents the potential difference between V2 and V1. The ECG recording was made by a young athlete (20 years) with an ECG body sensor. The need for the measurement emerged when a missing QRS complex was noticed on the phone's screen while the athlete was sitting and playing with the ECG sensor. Figure 4.5 shows a stable length of prolonged PR intervals, which is classified as a first-degree AV block. It was published that such a block is present in 5–13% of athletes [28].

In the ECG of the same person during sleep at around 4 AM, intervals with low and high BPM variability exist. An example of a high BPM variability is shown in Fig. 4.6, where the BPM changes from 63 to 39 in just a few seconds. Note that in the intervals with high BPM variability, the PR intervals did not change in proportion to

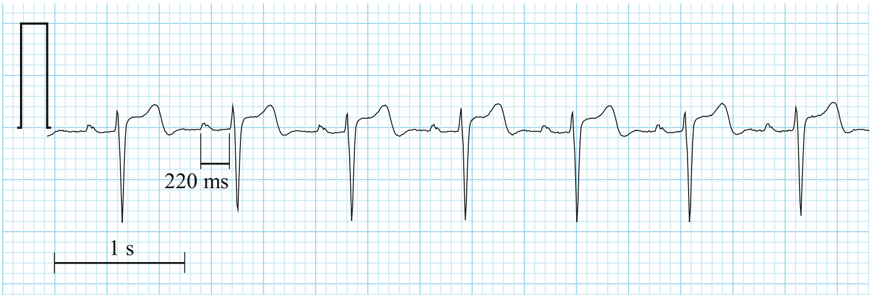

Fig. 4.5 The PR interval of a young athlete in the evening (7 PM) is constant but prolonged, indicating a first-degree AV block (PR > 200 ms). The heart rate is in a normal range of 67–70 BPM

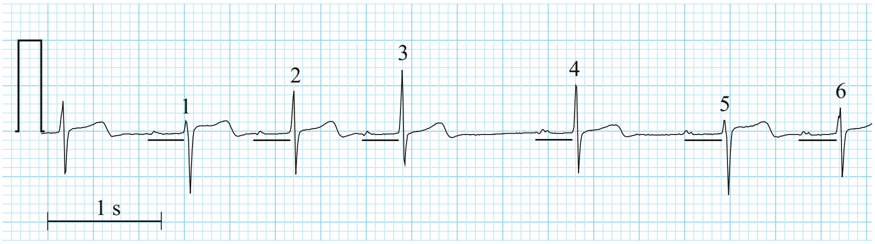

Fig. 4.6 The PR intervals do not change in proportion to the change of the RR intervals. The bars under the the PR intervals are of the same length (320 ms). The RR interval from the 3rd to the 4th QRS complex is much longer (1531 ms) than the other RR intervals, while the PR intervals of the shown beats do not differ significantly. The varying morphology of the QRS complexes is probably the influence of respiration on the differential lead vector

the RR intervals change, which indicates that different mechanisms govern the SN and AV nodes.

Quite a different situation is shown in Fig. 4.7 on the ECG of the same person at 4:39 AM. Not all atrial depolarizations are conducted to the ventricles. The conduction is blocked in a Wenckebach pattern, where successive PR intervals become longer until a block in the AV node occurs and the QRS complex is missing after the P wave. The shortest PR interval is the first one after the block. If we examine what is going on after the missing QRS complexes, we can see that in such PP intervals (indicated in Fig. 4.7 with their duration in ms: 1135, 1103 and 1047) there is a deficit of blood flow from the ventricles to the aorta and to the lungs, so that the blood pressure in the aorta falls well below the diastolic blood pressure. It could be expected that the baroreflex mechanism should speed-up the SN by lowering the vagal excitation in order to make these three PP intervals shorter. However, this was not the case, as all three PP intervals are longer than the previous ones.

The shortening of the PP intervals emerged only in the succeeding PP intervals. This is not an expected result and we have not yet found an explanation for such a behavior in the literature. It is known that such an AV block can emerge in athletes

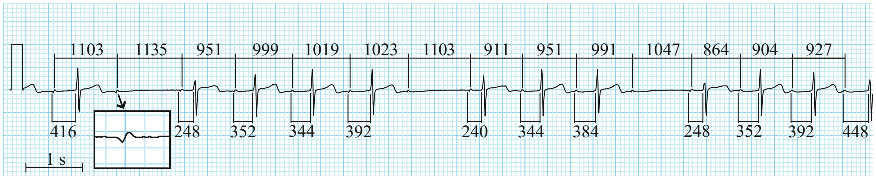

Fig. 4.7 Wenckebach pattern of a second-degree AV block during sleep. PR intervals are denoted below the ECG signal in ms. Note that the shortest PR interval is the first one in the sequence, while the longest PR interval is the last one. The PP intervals are indicated with their duration in ms above the ECG signal. A detailed P wave is shown in the zoomed frame

(type I second-degree AV block) and is most probably an expression of hypervagotonia related to physical training [27]. We noticed that the Wenckebach pattern of AV node's block was found only in sleeping periods with high HRV. The examination of the PR intervals at day-time, when the heart rate was high (90 BPM), revealed that the PR intervals were 3 times shorter, e.g. 144 ms at 4:35 PM, showing a wide range of adaptation mechanisms for the AV node delay time throughout the whole 24-h period.

Although the amplitude of the P waves in Fig. 4.7 is small ($< 50\,\mu V$), the quality of the digital recording and the visualization software enable magnification of the recorded ECG signal up to the quantization level (see the frame inserted in Fig. 4.7). In this way, the P waves and other details could be clearly seen and reproduced on the paper media. For the same reason, extensive filtering of the signal should be only an option in the post-processing phase. Therefore, we show such unfiltered signals in all figures of this chapter. It is high time that the industry qualified to produce ECG machines makes available, as a standard option, all the details of digital recordings for further analysis and research. Modern ECG machines produce excellent digital recordings, but the output is normally written only on a paper with poor resolution, which prevents detailed analysis because all details are lost. We encounter such examples in many scientific papers that offer reproductions of the ECG waveforms only from paper media with extraordinarily poor resolution.

4.6.3 Atrial Flutter During a 20-Day ECG Measurement

Finally, we present a case of a man (73 years old) with arrhythmia originating from the atria in a period of nearly 3 weeks. Again, as in the previous cases, a single-channel ECG sensor has been used with a great success. The user has reported that wearing the sensor during the 3-week period was a simple task because he had mostly forgot about wearing it.

The placement of the ECG sensor was the same as in the previous example, so that the potential difference (V2–V1) of the standard 12-lead ECG was measured. Soon after the placement of the sensor, on the first day, the ECG revealed a clear

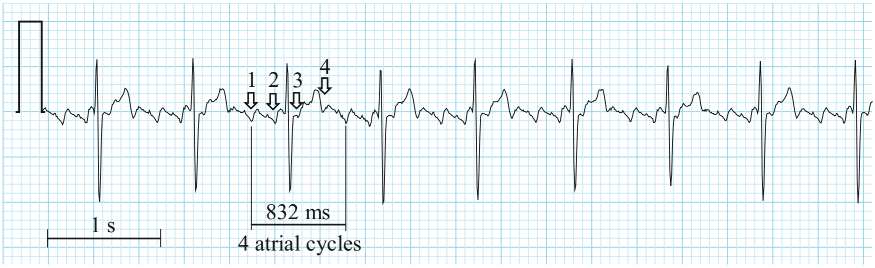

Fig. 4.8 Atrial flutter with atrial rate of 288 cycles/min (208 ms cycle period) with 4:1 conduction ratio to the ventricles. The ventricular rate is exactly 4 times lower than the atrial rate, i.e. 72 BPM

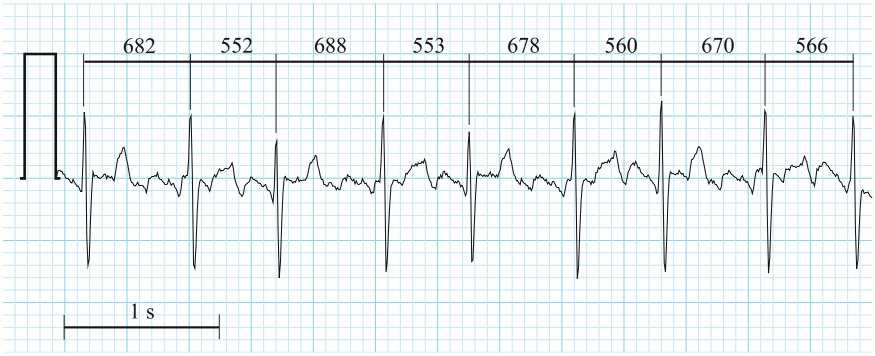

Fig. 4.9 Alternate atria-ventricle conduction. RR intervals are denoted with their duration in ms. The sum of 2 consecutive RR intervals is around 1237 ms, which produces an average ventricular rate of 97 BPM. The dominant atrial frequency is around 290 cycles/min and is not different from the situation shown in Fig. 4.8

atrial flutter pattern, shown in Fig. 4.8. If we look at the atrial waves just before the QRS complexes, we see that the atrial and the ventricular activities are coordinated, i.e., have the same phase, and that the time between the atrial waves preceding the QRS is constant. As the atrial rate is constantly at 288 cycles/min, the ventricular rate is 4 times lower.

At 6 PM of the first recording day, another atria-ventricle conduction pattern appeared, with an alternation of longer and shorter cycles (shown in Fig. 4.9). Note that the similarity of atrial waves is lost, indicating that an irregular and more complex depolarization pattern of the atria is present, although the regularity over 2 ventricular beats is still present. The only way for the autonomic system to control the ventricular rate is through a modulation of the conduction properties of the AV node.

During the night, the atrial flutter persisted, but the conduction ratio differed from that seen at day-time because of varying conduction ratios, as shown in Fig. 4.10. The latter "controlled" the average ventricular rate to a value of 49 BPM, although the atrial flutter frequency was still high (267 cycles/min). Note that each QRS complex starts nearly at the same phase with the atrial wave, just as in Fig. 4.8.

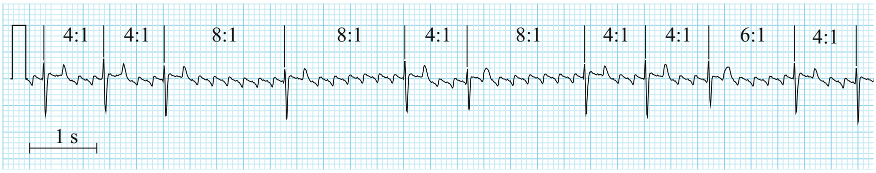

Fig. 4.10 Varying conduction ratios of the AV node "control" the average ventricular rate to 49 BPM, although the atrial flutter frequency is 267 cycles/min. The recording is from 1:30 AM

Similar situations persisted in the following days of the measurement, till the day 20, when the atrial flutter started to shift between irregular atrial waveforms of fibrillation and atrial flutter.

Even though the AF was discovered more than 100 years ago, its mechanisms and manifestation are not completely understood. Today we know that AF is the most prevalent arrhythmia, associated with other health problems and with a substantial cost. Long-term and high-quality ECG measurements can contribute to new findings in this area. We expect that other manifestations of AF, e.g. paroxismal AF or silent AF [29], will become more and more investigated by using body sensors for long-term ECG measurements.

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