Arrhythmia database with annotated intracardial atrial signals from pediatric patients undergoing catheter ablation

Richard Redina[1,2], Jakub Hejc[2,3], David Pospisil[4], Marina Ronzhina[1], Petra Novotna[1], Zdenek Starek[2]

[1] Department of Biomedical Engineering, Faculty of Electrical Engineering and Communications, Brno University of Technology, Brno, Czech Republic
[2] International Clinic Research Centre, St. Anne's Hospital, Brno, Czech Republic
[3] Department of Pediatric, Children's Hospital, University Hospital Brno, Brno, Czech Republic
[4] Department of Cardiology, University Hospital Brno, Brno, Czech Republic

Abstract

Conventional surface ECG analysis has brought a breakthrough in the diagnosis of heart diseases in the last century. With improvements in technology, doctors are now able to read ECGs using catheters placed directly in the heart. Signals obtained in this way may herald a further shift in diagnostic capabilities. Early detection of cardiac arrhythmias is still one of the challenges in medicine. For this task, intracardiac ECG recordings from presented database can be a valuable source of information. The recordings were obtained during electrophysiological procedures on paediatric patients with arrhythmias.

The database consists of a total of 326 records, from one hundred patients. For each record, global annotation with arrhythmia findings and local annotations with atrial activity onset/offset are available. Annotations capturing atrial activity were manually created by the experienced electrophysiologists. A large proportion of the records (n = 191) contain only sinus rhythm. Ventricular preexcitation (n = 58) and atrial premature beat (n = 47) were the most common findings in the database. We hope that the database presented in the paper will open new possibilities in the research of cardiac arrhythmias as well as in the improvement of wave detection in ECG or in the overall ECG delineation.

1. Introduction

One of the most important commonly sensed biosignals is the ECG, which represents electrical activity of the heart. It is standardly recorded from the surface of the body. The individual oscillations in ECG have their own physiological interpretation and show the propagation of the depolarization wave through the myocardium. The ECG has become the gold standard for the evaluation of many pathologies, such arrhythmias [1]. These are heart rhythm disturbances that can lead to circulatory instability, stroke or even death.

Clinical treatment of cardiac arrhythmias can be divided into two main branches - pharmacological and non-pharmacological. The latter includes radiofrequency ablation - damaging of the tissue involved in arrhythmia by radiofrequency energy, which is applied with the catheter inserted into the heart chambers. The procedure prevents further development of the heart rhythm irregularities. Besides the ablation catheter, several diagnostic catheters are used simultaneously. The signals from these catheters help to orientate in the heart and to verify the effectiveness of the therapy. [2]

Intracardiac ECGs are the unique source of valuable information about the heart's function. For example, they seem to be useful for refining P-wave positions with significantly improved success rate [3]. However, these recordings are not easily available to wide research community today. On the contrary, there are many publicly available databases of standard ECG recordings, such as MIT-BIH arrhythmia database [4], Europian ST-T database [5] or St Petersburg INCART 12-lead Arrhythmia Database [6], etc. These databases usually offer common surface ECGs from one to twelve leads, with sampling frequency of the records varying between 250 and 360 Hz.

In this paper, we introduce a new database containing simultaneously recorded 12-lead surface and 5-lead inctracardiac ECG from a total of one hundred patients. Since these were pediatric patients undergoing electrophysiological intervention, the records are rich in various arrhythmias. The sampling frequency of the records is 2000 Hz, which provides a higher temporal resolution than most other databases. For each record, global annotation of arrhythmias is available. Each intracardiac signal is accompanied by annotation indicating atrial activity.

2. Methods

2.1. Subjects

The measured data come from one hundred patients aged twelve to seventeen years who underwent electrophysiological procedure at the Children's Hospital, University Hospital Brno, Brno, Czech Republic. The measurements were performed with the approval of the ethics committee. During the procedure, a 12-lead ECG was measured and recorded along with a 5-lead intracardiac ECG. From these recordings, a total of 326 short segments were extracted where arrhythmic episodes are captured. These episodes were validated by experienced electrophysiologists. The length of the extracted segments ranges from 6.4 to 12.2 seconds. The basic description of the data in the database is summarised in Table 1. Not all findigs in the database are exlusive for each record.

Table 1. Basic description of database. Findings are represented by their frequency.

Attribute	Value
Number of subjects	100
Age [years]	14.0 (12.0-17.0)
Sex: males	52
Length of records [s]	8.5 (6.4 - 12.2)
Number of records	326
Sinus rhythm	191
Ventricular pre-excitation	58
Atrial premature beat	47
AV node re-entry tachycardia	45
AV re-entry tachycardia	40
Ventricular premature beat	40
Ventricular stimulation	35
Atrial fibrillation	33
Junctional rhythm	22
Atrial stimulation	19
Left bundle branch block	9
Focal atrial tachycardia	8
Right branch block	7
Atrial flutter	5
1st degree AV block	3

2.2. Data acquisition

As mentioned above, all signals from the database were captured during the electrophysiological procedure. This procedure is initiated by induction the patient under procedural sedation using propofol. Other possible medications used in this examination are isoprenaline and adenosine. Two diagnostic and one ablation catheter are used during these procedures. The most important one of them for measuring the atrial signal and monitoring the propagation of the depolarizing wave is the one that is placed into the coronary sinus (CS). The specific location of the catheter is shown on the peroperative X-rays in the Figure 1.

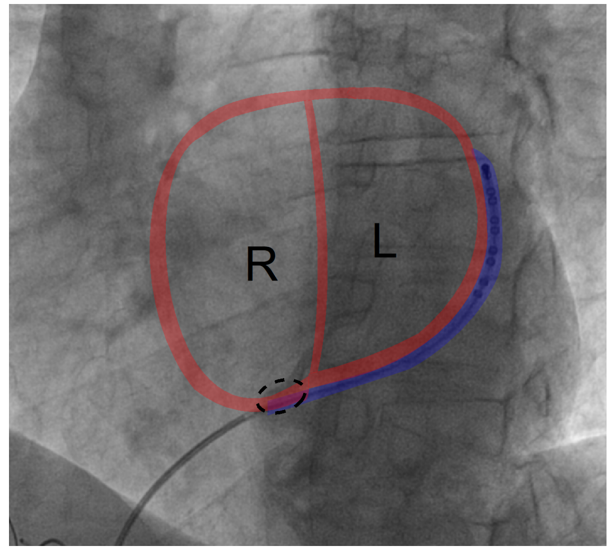

Figure 1. Chest X-ray image of patient in left anterior oblique projection (LAO) at an angle of 30 degrees. Diagnostic catheter is placed in the coronary sinus (blue) via the ostium sinus coronarius (black dashed ellipse) in the right atrium (R). The coronary sinus goes around the left atrium (L).

Through the vena cava inferior it enters the right atrium, where it is guided by the operator into the coronary sinus. A 10-polar catheter was used in combination with a St. Jude WorkMate 4.2 EP system with a sampling rate of 2000 Hz and a voltage resolution of 78 nV/LSB. The measurement includes the use of a notch filter to attenuate the 50 Hz frequency and a high pass filter with a cutoff frequency of 0.1 Hz. The second, 4-polar diagnostic catheter is inserted into the area around the AV node and His bundle. The last one is the therapy catheter used to apply radiofrequency energy. This catheter does not record ECG and, thus, it is not relevant for the database.

2.3. Data annotation

The annotations can be divided into two subgroups. The first one is the global annotation created for each record. It contains information about the instrument specifications and a summary of the pathological findings present in the signal. The arrhythmias were registered during the examination based on standard electrophysiological protocols. Some of these findings arose solely as a result of the examination procedure, such as junctional rhythms caused by ablation in the AV nodal region due to AV nodal re-entry tachycardia.

The second part of annotation report includes specific local annotations of left atrial activity measured in the CS leads. These annotations were manually created by a team of electrophysiologists in the SignalPlant software environment [7]. The annotation of the onset and offset of atrial electrical activity refers to all 5 leads, not to each channel separately. The approximate position of the onset and offset was determined by estimation according to standard electrophysiological procedures. An example of intracardiac ECGs with indicated atrial activity is shown in Figure 2. An important part of the data annotation process was the creation of software packages for conversion of raw signals into a structured data format compatible with the SignalPlant environment as well as other platforms (Python, MATLAB, etc.).

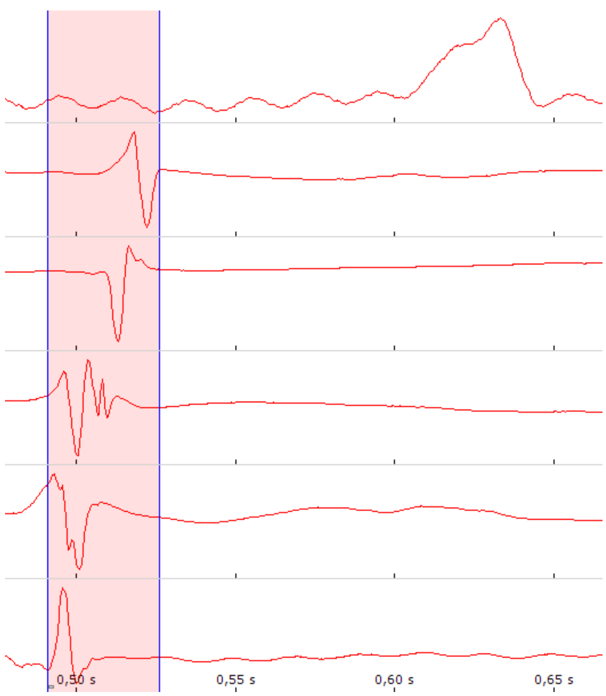

Figure 2. Illustration of one selected heartbeat from the database. From top to bottom: surface leads V5 and V6 and intracardiac leads cs1-2, cs3-4, cs5-6, cs7-8, and cs9-10. Atrial activity (red block) is more evident in the intracardiac recordings compared to the surface ECG.

3. Results and Discussion

The database consists of a total of 326 records, from one hundred patients. It contains a total of 14 different types of rhythm. A large amount of the records (n = 191) represents sinus rhythm exclusively. Ventricular preexcitation (n = 58) and atrial premature beat (n = 47) were the most common findings in the database. One of the database advantages is that the signals come from paediatric patients. In combination with annotated atrial activity it makes the database largely unique. The existence of these records is conditioned by the need to perform electrophysiological procedures in children. This demand stimulates the need to create algorithms that are able to detect arrhythmias and target the pediatric population. On the other hand, the database does not capture arrhythmias common in the adult population. For example, atrial fibrillation is rare in children, but its prevalence in population increases with age. [8]

Another benefit of the database is a high sampling frequency and, consequently, high temporal resolution of data. As mentioned above, the usual sampling frequency for ECG recordings is in the range of 250-500 Hz. These values are sufficient for surface ECG, as all the structures observed on ECG occur at frequencies up to 100 Hz [9]. Higher temporal resolution is necessary to successfully investigate intracardiac signals as they capture events lasting a shorter time compared to surface ECG. The use of a higher sampling frequency opens up new possibilities for investigating both surface and intracardiac ECG signals. It has recently been shown that analysis of high-frequency intracardiac ECG signals can early detect cardiac ischemia [10].

The final product is stored as a hierarchical data format version 5 (HDF5) for each signal segment. The file structure consists of four main datasets - *Data, ChannelSettings, Info*, and *Marks*. The first dataset contains 19-lead ECG (twelve surface, 5-lead CS and 2-lead His) along with a signal that captures whether artificial stimulation has been performed. The signal is stored as integers. For easier file manipulation, the length of the recording was limited to 360,000 samples (180 seconds). The second and third datasets contain technical information for signal visualization in SignalPlant. The last dataset is local annotations capturing atrial activity. Each individual marker includes a *SampleLeft* and a *SampleRight* indicating the beginning and the end of atrial activity, respectively.

The advantage of the selected format is the possibility of adding metadata that relates either to individual datasets or to the file as such. A single set of metadata was created for the entire signal segment, which includes patient demographics, instrument settings (including sampling rate and resolution), findings information, and the measurement record.

4. Conclusion

We believe, that the unique database presented in the paper will create a room for further advanced analysis of heart rhythm. In future research, the database can be used to develop the algorithms for signal pre-processing and removing the noise, atrial/ventricular activity segmentation, or classification of selected arrhythmias.

The detection of P waves in surface ECGs is still challenging task. Poorly pronounced amplitude deflection and low-frequency character of P waves often lead to incorrect determination of their onset/offset and peak. However, the duration of the P wave as well as the length of the PQ interval are crucial for ECG delineation and detection of various arrhythmias. Presented database may be applied to refine algorithms for P wave detection, as our atrial activity annotation is based on highly informative intracardiac signals rather than surface ones. This makes the annotations as accurate as possible, as they reflect the exact time the depolarizing wave crossed the left atrium. Accurate detection of P waves in patients is complicated by arrhythmia manifestations in ECGs [11]. Our database could be especially useful in such applications, as intracardiac records - contrary to the surface ECGs - successfully capture even atrial activity overlaid by the ventricular one (e.g. in case of AV nodal re-entry tachycardia).

The presented database can be used for developing the methods for signal processing analysis, as was previously presented in [12]. In the future, we expect including more subjects in the database. This extension should offer the possibility of investigating other arrhythmias such as atrial fibrillation or flutter, ventricular and atrial extrasystoles, or AV blocks of various degrees. With more recordings, it will be possible to develop advanced deep learning approaches, which could bring significant improvements in arrhythmias classification or ECG delineation. To the best of our knowledge, there is no other available database with both intracardiac and surface ECGs supplemented by atrial activity annotations. Our database will be available on request from the corresponding author.

Acknowledgments

RR is the Brno Ph.D. Talent Scholarship Holder funded by the Brno City Municipality project "Advanced Detection of Cardiac Arrhythmias Using Intracardiac ECG and Deep Learning Methods."

This publication was written at Masaryk University as part of the project "Novel imaging, computing and analytical methods in cardiovascular diseases diagnostics and monitoring" number MUNI/A/1462/2021 with the support of the Specific University Research Grant, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2022.

References

[1] Stracina T, Ronzhina M, Redina R, Novakova M. Golden standard or obsolete method? review of ECG applications in clinical and experimental context. Frontiers in Physiology April 2022;13. URL https://doi.org/10.3389/fphys.2022.867033.

[2] Koca S, Akdeniz C, Tuzcu V. Transseptal puncture for catheter ablation in children. Pediatric Cardiology February 2019;40(4):799–804. URL https://doi.org/10.1007/s00246-019-02069-4.

[3] Lenis G, Pilia N, Oesterlein T, Luik A, Schmitt C, Dössel O. P wave detection and delineation in the ECG based on the phase free stationary wavelet transform and using intracardiac atrial electrograms as reference. Biomedical Engineering Biomedizinische Technik February 2016;61(1):37–56. URL https://doi.org/10.1515/bmt-2014-0161.

[4] Moody G, Mark R. The impact of the MIT-BIH arrhythmia database. IEEE Engineering in Medicine and Biology Magazine 2001;20(3):45–50. URL https://doi.org/10.1109/51.932724.

[5] Taddei A, Distante G, Emdin M, Pisani P, Moody GB, Zeelenberg C, Marchesi C. European st-t database, 2000. URL https://physionet.org/content/edb/.

[6] Tihonenko V, Khaustov A, Ivanov S, Rivin A. St.-petersburg institute of cardiological technics 12-lead arrhythmia database, 2007. URL https://physionet.org/content/incartdb/.

[7] Plesinger F, Jurco J, Halamek J, Jurak P. SignalPlant: an open signal processing software platform. Physiological Measurement May 2016;37(7):N38–N48. URL https://doi.org/10.1088/0967-3334/37/7/n38.

[8] Friberg L, Bergfeldt L. Atrial fibrillation prevalence revisited. Journal of Internal Medicine August 2013;274(5):461–468. URL https://doi.org/10.1111/joim.12114.

[9] Surda J, Lovas S, Pucik J, Jus M. Spectral properties of ecg signal. In 2007 17th International Conference Radioelektronika. IEEE, 2007; 1–5.

[10] Omer N, Bergman E, Ben-David T, Huri S, Beker A, Abboud S, Granot Y, Meerkin D. Changes in high-frequency intracardiac electrogram indicate cardiac ischemia. J Cardiovasc Transl Res February 2022;15(1):84–94.

[11] Saclova L, Nemcova A, Smisek R, Smital L, Vitek M, Ronzhina M. Reliable p wave detection in pathological ECG signals. Scientific Reports apr 2022;12(1). URL

[12] Hejč J, Pospíšil D, Novotná P, Pešl M, Janoušek O, Ronzhina M, Stárek Z. Segmentation of atrial activity in intracardiac electrograms (egms) using convolutional neural network (cnn) trained on small imbalanced dataset. In Computing in Cardiology 2021. Computing in Cardiology 2021: Computing in Cardiology 2021, november 2021; 1–4.

Address for correspondence:

Richard Redina
Department of Biomedical Engineering
Brno University of Technology
Technicka 3058/12, Brno, 61200
Czech Republic
E-mail adress: 195715@vut.cz