The STAFF III Database: ECGs Recorded During Acutely Induced Myocardial Ischemia

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Abstract

The STAFF III database was acquired with the aim of better understanding the ECG signatures observed during acute ischemia, with special focus on high-frequency QRS components. The database contains recordings from 104 patients undergoing elective balloon percutaneous coronary intervention. The database has not only been analyzed in numerous clinical studies, but also turned out to be an excellent tool for methodological development. Its use has, by far, exceeded the original aim. Inspired by this fact, the database has now been made publicly available at Physionet.

1. Introduction

The STAFF III database was acquired in 1995–96 at the Charleston Area Medical Center (WV, USA), where single prolonged balloon inflation had been introduced to achieve optimal results of the elective balloon percutaneous coronary intervention (PCI) procedure, replacing the typical series of brief inflations. The database consists of ECG recordings from 104 patients, thus accounting for substantial inter-patient variability due to prolonged balloon inflation (before the stent era) as well as variability in rhythm and waveform morphology; Fig. 1 illustrates changes observed during balloon inflation. Only patients receiving elective balloon PCI in one of the major coronary arteries were included. Patients suffering from ventricular tachycardia, undergoing an emergency procedure, or demonstrating signal loss during acquisition, were excluded. The database was originally acquired for analyzing high-frequency QRS components during acute ischemia [1]. A description of the context and history of the database is found in [3], and a review of methodological development in [4]. The database is publicly available at *Physionet* (identified by the doi:10.13026/C20P4H) [2].

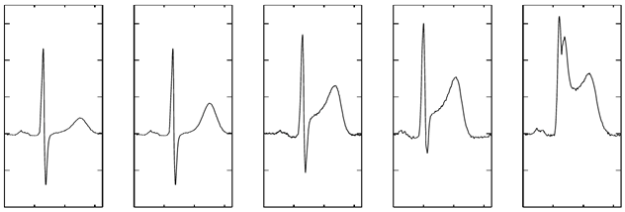

Figure 1. From left to right: Sequential ECG changes observed during the course of myocardial ischemia.

2. Data Acquisition

The occlusion procedure was defined as follows. Pre-inflation (baseline) ECGs were acquired for 5 min at rest in supine position in either the patientt's room at the ward, in the catheterization laboratory, or both, prior to any catheter insertion. Inflation ECGs were acquired during a single, or in some cases multiple (up to five times), balloon inflations in each patient. The mean inflation time was 4 min 23 s, ranging from 1 min 30 s to 9 min and 54 s. In 86 inflations, the recording was started some time before balloon inflation (4 to 205 s). Moreover, in some cases, the recording was continued after balloon deflation, with a postinflation period >60 s in all but 11 inflations. All time instants related to balloon inflation/deflation were manually annotated. Post-inflation ECGs were acquired for 5 min at rest in supine position in either the cath lab or the patientt's room at the ward, or both.

The database contains a total of 152 occlusions in the major coronary arteries, distributed as 58 occlusions in the left anterior descending (LAD) artery, 59 in the right coronary artery (RCA), 32 in the left circumflex artery (LCX),

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Figure 2. ECG with the annotated onset of balloon inflation.

and 3 in the left main (LM) artery. Based on ECG criteria, 35 patients had previous myocardial infarction.

The database consists of standard 12-lead ECG data. Standard electrode placements were used for the precordial leads, whereas the limb leads were obtained with the Mason–Likar electrode configuration to reduce noise originating from skeletal muscle. Data acquisition was based on custom-made equipment by Siemens–Elema AB, offering an extraordinary input amplitude range. The ECG was digitized at a sampling rate of 1000 Hz and an amplitude resolution of 0.625 μV. These specifications ensured that high-resolution digital signals could be produced so that high-frequency components, as well as other subtle electrophysiological phenomena, could be analyzed.

Dye injections during catheterization and angiography may cause changes in ECG morphology, and therefore injections were annotated. Since far from all injections were annotated, database users are advised to be cautious when brief changes in the ECG are observed that mimic the dynamics of the known dye injections.

3. Data Files

The clinical information and annotations are included in a companion spreadsheet, see Table 1 for details on data types. The time instants of balloon inflation/deflation and the contrast injection are also provided as annotator files.

Each recording is defined by the data files **.dat* and **.hea*, together with the annotation file **.event* which includes the time instants of balloon inflation/deflation and contrast injection. Figure 2 displays an ECG with the annotated onset of balloon inflation.

In some files, additional inflations have been identified not originally indicated. These additional inflations are included in the **.event* file.

For records containing more than one inflation, the annotated time until inflation (D0), for the second and subsequent inflations, is not strictly the time at which the balloon is inflated, as D0 includes the duration of the previous pre-inflation(s), inflation(s), and post-inflation(s), see example in Table 1.

4. Clinical Applications

Coronary artery occlusion reduces myocardial blood flow and thus induces ischemia locally in the affected myocardial area. This ischemia most often produces considerable change the ECG morphology. The changes are explored for detecting, monitoring, and quantifying ischemia. While the ST level is the most widely used index, it is known to suffer from poor performance when used for detecting ischemia, thereby limiting its usefulness in clinical practice.

The number of studies involving the STAFF III database has increased considerably over the years, as it has been found highly adequate for several other research problems than high-frequency QRS analysis. Although the original motivation for acquiring the database was clinically oriented, the database has been found most valuable for developing, improving, and evaluating a wide range of signal

Table 1. Data types

Data	Example record #39
Record #	39
Age (years)	48
Sex (m/f)	m
Baseline record at room (BR)	39a
First baseline record at cath-lab (BC1)	39b
Second baseline record at cath-lab (BC2)	-
First inflation record (BI1)	39c
Occluded artery in record BI1	mid LAD
Occlusion time (in s.) Inflation duration (in s.) Reperfusion duration at BI1 (in s.)	0 285 7
Contrast injection at BI1	-
Second inflation record (BI2)	39c
Occluded artery in record BI2	prox LAD
Occlusion time (in s.) Inflation duration(in s.) Reperfusion duration at BI2 (in s.)	292 200 30
Contrast injection at BI2	-
Third inflation record (BI3)	39c
Occluded artery in record BI3	prox LAD
Occlusion time (in s.) Inflation duration (in s.) Reperfusion duration at BI3 (in s.)	522 137 106
Contrast injection at BI3	502;707
Fourth inflation record (BI4)	39d
Occluded artery in record BI4	prox LAD
Occlusion time (in s.) Inflation duration (in s.) Reperfusion duration at BI4 (in s.)	0 152 60
Fifth inflation record (BI5)	39d
Occluded artery in record BI5	prox LAD
Occlusion time (in s.) Inflation duration (in s.) reperfusion duration at BI5 (in s.)	212 117 36
First post-inflation record at cath-lab (PC1)	-
Second post-inflation record at cath-lab (PC2)	-
First post-inflation record at room (PR1)	39e
Second post-inflation record at room (PR2)	-
Prior MI location	anterior

processing techniques [4].

Considerable research has been done on the database, including the following clinical aspects:

- Time course of ischemia-induced changes in repolarization indices. Figure 3 illustrates the ST level before, during, and after balloon inflation.
- Time course of ischemia-induced changes in indices describing ventricular depolarization, and evaluation of variability/reproducibility across patients. Figure 4 illustrates QRS upslope during control (two recordings), occlusion, and reperfusion. The reperfusion effects after artery reopening and/or contrast injections can be observed.
- Spatial distribution of ischemic markers by analysing their signature at different leads. Eventually this can be correlated to the occluded artery. Figure 5 illustrates the variability in QRS up- and downslope for different leads.
- Implications of myocardial ischemia on T wave alternans. Figure 6 illustrates the dynamics of repolarization alternans amplitude and ST level.
- Ischemia detection exploring the stronger non-linear response of QRS angles to ischemia. Figure 7 illustrates QRS angle and ST dynamics.

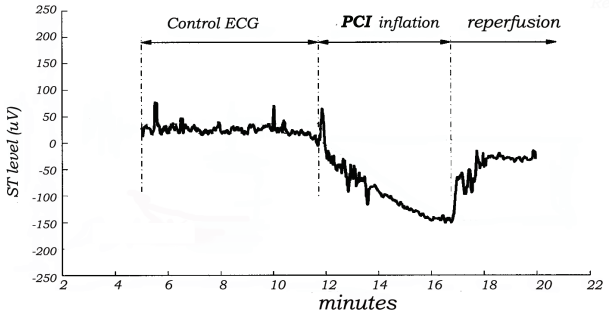

Figure 3. ST level dynamics during control, occlusion, and reperfusion (adapted from [5]).

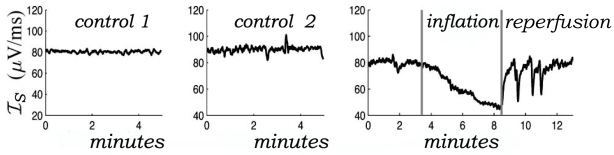

Figure 4. QRS upslope ($\mathcal{I}_S$) dynamics during control, and occlusion/reperfusion (adapted from [6]).

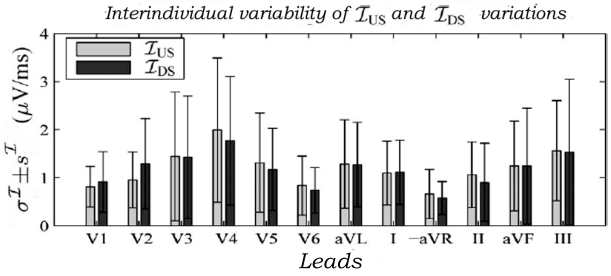

Figure 5. Variability in QRS up- and downslope across leads (adapted from [6]).

5. Contributors

The primary investigator Dr. Stafford Warren designed the study protocol together with Dr. Galen Wagner at Duke University Medical Center (Durham, NC, USA); Dr. Michael Ringborn was responsible for data acquisition. The database has been distributed by Prof. Leif Sörnmo, who was responsible for the acquisition equipment and software.

Dr. Wagner was the leader of the STAFF studies, and promoter of the clinical design and the analysis performed

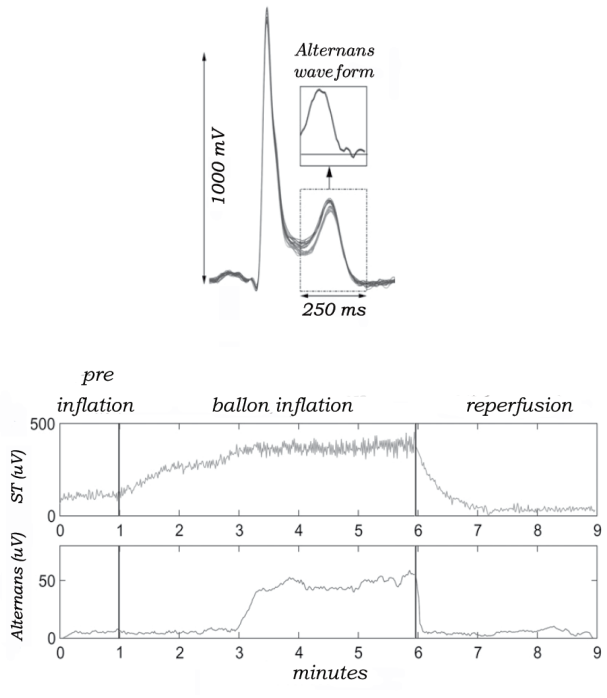

Figure 6. Repolarization alternans and ST level before, during, and after balloon inflation (adapted from [4]).

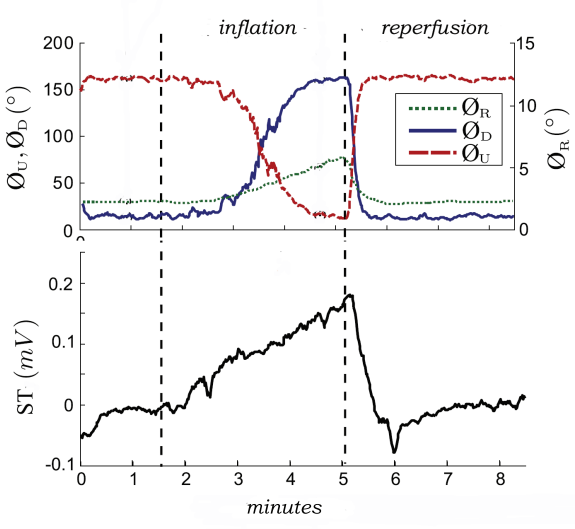

Figure 7. QRS angles (upwards $Ø_U$, downwards $Ø_D$, and middle $Ø_R$) and ST level (adapted from [7]).

on the data. He was a strong proponent of making the database public.

6. Conclusions

The STAFF III Database is now publicly available on Physionet to stimulate research on transient phenomena in the ECG associated with acute myocardial ischemia. The database is annotated with respect to the important characteristics of acute ischemia, i.e., the onset/end of balloon inflation and the occluded artery. The ischemia so generated corresponds to total occlusion. The time for contrast injection is also included, allowing the evaluation of contrast-induced effects on the ECG. Control recordings before and after occlusion are included. The database offers an excellent testbed for evaluating methods and techniques aimed at quantifying myocardial ischemia.

Acknowledgements

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