Study of high-frequency electrocardiogram *

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Abstract-High-frequency electrocardiogram (ECG) has been developed for more than 40 years and it is still not applied to clinic because there are some facts of causing high-frequency ECG (HFECG) and its mechanism are not understanding well, and the idiosyncrasy of patients appears not too clear formerly. We are interest in study of high-frequency information (HFI) in QRS complex and use animal model and some extraction methods to make sure its producing mechanism. The purpose of this article is to describe some good results which could explain some phenomena, that is high-frequency notching located on QRS complex is associated with myocardial injuries in which the small injury area exactly related with injecting formalin or ligaturing coronary artery. We also pointed that notching processing are necessary, and supplementary parameters should adopted, that the HFI has very useful value of idiosyncratic, local, early and dynamic characteristics for early diagnosis.

Key words: HFECG, Notch, Slur, Formalin injection, Ligature of coronary arteries

Ⅰ. INTRODUCTION

Scientists have known patients surviving myocardial infarction has been found to be increasing notches and slurs, and the reason is not understand well. As everyone knows, heart diseases are one of caused patient high death rate. So attaching important extent to study of some of heart diseases by vast scientists and physicians are also known to all. However, up to now, there is not any good way to find early symptoms of heart diseases in clinical condition and to cure them in time currently because the active state of human heart is so complicated and its diversification of effective facts. In the early 1950's Langner reported the first studies of high-frequency ECG (1952; 1953) (1)(2)(3). Since 1960's, 1970's and 1980's, some scientists worked on the study of the high-frequency ECG in different ways. They gained many valuable results and developing methods of the first derivative, spectrum and computer analysis, anatomic experiment and propelling the studies of the high-frequency ECG forward developing in depth (4)(5)(6)(7)(8)(9)(10). But the exact value for clinical use and the producing mechanism were not made clear explanation. We have been working the research area for more then ten years and got useful results in which partition of early studies has been reported(11).

However existing notches and slurs are no sex difference and they all exist notches and slurs from children to adults (12)(13). We have developed foundation research on HFI and establish their causality relationship in order to make the HFECG with physiological theory and clinical diagnostic significance. It is the purpose of this study to carry out essential investigation created a small area of injury in the wall of the left ventricle based on acute and chronic experiments with dogs.

Actually, the HFECG contains more information about heart activity than clinic ECG, not only myocardial injury, for example breath suffocation could also be reflected by pathological notching increase.

Ⅱ. MATERIAL AND METHODS

Twenty five dogs, weighting from 8 to 15 kilograms, were used to do experiments in more than 10 years. Physical examination of each one was only tested by audio-visual before experiment. After that, they were used as research subjects if the heart is not abnormal. Each one was lightly anaesthetized by an injection of abdominal cavity of 2% pentobarbital and injected with approximately 1 ml per kilogram of body weight in order to reject the myoelectrical interference then wide band electrocardiogram of 12 leads was recorded and formed as contrast pattern with examinational ECG. Next, a thoracotomy was performed and the experiment was started if the heart was normal without congenital and organic diseases. Some dogs were anaesthetized by an injection of abdominal cavity of pentothal but most of them were anaesthetized by 2% pentobarbital and injected with approximately 1.3-1.7ml per kilogram of body weight. A module structure computer system designed by ourselves is used for animal experiments and for real-time acquiring, processing and displaying data so as to guide the experimental process toward correct progress.

There were fourteen dogs for chronic observation, and nine dogs were re-operated to examine the results and 7 of the 9 dogs were got their hearts out to cut sections of myocardial tissues for microscopic examination after two month raising. Under the microscope to observe the tissues of endocardium, we have found a segment of loose area among myocardial fibers, found few proliferation of lymphocyte and neutrophilia leukocyte in the endocardium and the epicardium. One of the dogs had a segment of infarction area in which it was under endocardium near the apex of left precardiac wall after ligatured 63 days. The area was 8 x 1.6mm. It was a pathological change of cicatricial phase. And another dog also had a segment of infarction

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Abstract

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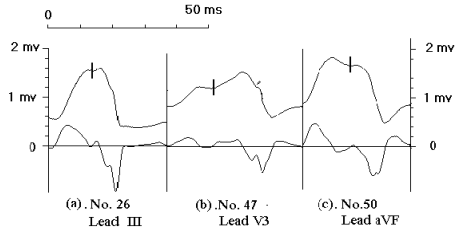
area in the same myocardial location with 4.5 x 3.2mm and got the same pathological change.

The nine dogs are and were measured with different period using different methods, such as once every half hour, one hour or every 4 hours after heart operation and so on. Then they measured once every day after one day or two days even measured once every two or three days after several days from operation till second operation.

Ⅲ. RESULTS

Wide band ECG contrasted with the 25 normal dogs have some notches and slurs on QRS complex of ECGs shown in Fig.1.

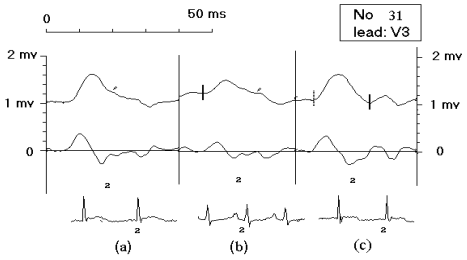


(a) A notch existed, parameters with 1.25ms width, 24.4uv height, located at 14.00ms.
(b) A notch existed, parameters with3.25ms width, 29.5uv height, located at 13.50ms
(c) A notch existed, parameters with 1.75ms width, 29.3uv height, located at 21.25ms.

Fig. 1 The wide-band QRS complex in healthful dogs.

Their numbers and locations were different from each other because of the individual difference. But they could be distinguished one from the others which were with pathological characters. The high-frequency components (HFC), especially were observed within several minutes of localized myocardial injection with formalin and persisted during the following experimental period of hours. And the components, clear-cut notches, were also found easily after ligaturing coronary arteries. Clear-cut notching was measured affirmatively after ligaturing one hour later. Clear-cut slurs also and always appeared within certain minutes (such as 20 minutes) of myocardial injury for either formalin injecting or ligaturing coronary arteries but they were non-idiosyncratic. Fig.2 Illustrates the type of notches caused by the ligatured coronary arteries.

As a whole, both ligaturing coronary arteries and injecting formalin to injure myocardial tissues could produce obvious raise and change of HFCs. It has to be noted that we have analyzed the characters of notches and slurs before and after myocardial injury and found that their expression was the most obvious during the following half- or one-hour period of injury. On the basis of long-term chronic observational experiments, the numbers and locations of HFCs were unstable could change a lot during the following day period (such as within 4-7 days or even more) of observation. Some of high-frequency components in dogs got into stable state, some returned to normal. But wide band ECG for other two dogs got T-wave taller in chest lead V2 and appeared pathological Q_wave in lead V3 for a short while during the period of the middle observation. Some dogs had ST segment elevation within 1.5-2.5 hours of the ligature coronary arteries but on the contrary, HFCs reduced. Some other dogs (one for formalin injection and another for ligature) obviously changed HFCs only when wide band ECG were measured immediately after cardiac injury but the traditional low-frequency components of ECG didn't any changed. Clear-discernible notches were produced in 14 acute experimental dogs, and they always appeared within one hour of the myocardial injection with formalin and persisted during the following one-hour period of observation. The similar results happened in another 5 chronic experimental dogs, and they measured notches after 10 minutes or 60 minutes of the localized myocardial injury and appeared clear. But the HFCs are not stable and always changed during the following 4-7day or even more period of injured by chronic ligature or injected with formalin. In two dogs, pathological notches that were still present but change frequently in the following days after injury. Then these notches had disappeared completely. In some other dogs, the pathological notching always appeared during the following day period of observation after injury and passing through the following 17 day period changing. In 7 chronic examining dogs, there were 6 dogs for research of ligaturing coronary arteries and 1 for formalin injection left.



(a) Control state, a slur existed, parameters were 1.75ms width, 24.4 uv height, located at 21.50ms.
(b) At once after ischemia state, a new notch appeared, parameters were 2.25ms width, 26.9uv height, located at 16.75ms.
(c) An hour after ischemia state, an abnormal notch existed, parameters were 4.50ms width, 146.5uv height, located at 23.75ms.

Fig. 2 HFCs changes caused by ligaturing coronary ateries.

Whole wide-band ECG of 25 normal dogs physical examination indicated that their parameters of HFCs ranged within width of 3.8 ms and amplitude of 84.0 uV after computing them. For this reason, we have defined above values as threshold. We call the notching as pathological one if its parameters are over the threshold. Other wise, it is called normal one which could be distributed all over the rage of whole QRS complex.

Table 1. Notch and Slur Distribution on QRS Complex under Different Condition

Number of dogs	lie on dog's back									Lie on dog's right side								
	Slurs on QRS				Notches on QRS					Slurs on QRS				Notches on QRS				
	initial	iddle	terminal	sub-total	initial	middle	terminal	sub-total	Total	nitial	middle	terminal	Sub-total	initial	middle	terminal	sub-total	Total
23	4	1	1	6	1	2	0	3	9	8	6	2	16	1	0	0	1	17
24	7	4	7	18	0	3	0	3	21	7	10	0	17	2	1	0	3	20
25	3	9	5	17	2	1	1	4	21	6	10	2	18	1	1	0	2	20
26	1	9	8	18	6	4	1	11	29	5	13	13	31	2	5	2	9	40
28	5	8	2	15	1	2	0	3	18	1	1	0	2	4	0	0	4	6
29	2	5	3	10	2	1	1	4	14	3	0	0	3	3	0	0	3	6
30	4	9	9	22	2	2	1	5	27	4	10	7	21	2	0	1	3	24
31	5	8	7	20	0	0	0	0	20	7	3	5	15	1	2	0	3	18
Total	31	53	42	126	14	15	4	33	159	41	53	29	123	16	9	3	28	151

Most all of health dogs have certain notches and slurs in QRS complex and those HFCs are distributed in whole QRS complex and different position has different pattern but the numbers in total are the stable, not changing too much shown in table I. Those components mostly located in front of R_wave (about 90%), rest located the terminal of R_wave. The component location was steadily shifted to terminal along with injury serious level, for example after ligaturing 30 minutes later, about 60% components located the terminal part of R_wave.

Ⅳ. DISCUSSION

Our experiments indicate that wide-band ECG of all dogs have notches and slurs which distributed different interval of QRS complex and had different numbers. After thorough computing their parameters were not the same but within certain scope. This phenomenon was showing no difference to notched ECG apparently healthy subjects including children, youth, adults and old people (12) (13). In this case, it is no able to explain notches and slurs on normal human and dogs by myocardial-local injury or pathological changes.

We have considered, by experimental studies, that the reason for causing HFCs notches and slurs (especially notches) may have normal or pathological case, that is normal and pathological notching as well as sluring. A very general consideration as to the cause of notching is that a smooth wave front of ventricular depolarization caused by action potential propagation either approaching or receding from the exploring electrode is synchronized or fragmented.

We supposed that there have permeability changes of ionic channel caused by physiological reasons that could produce "interferential factors" to influence parts of muscle action potential propagation carried from cell to cell. The threshold potential and the velocity of propagated wave in cardiac muscle, and the part pathological change could produce "adjacent interference" to induce those abnormal notches and slurs.

The pathological cut sections for microscopic examination was made for two dogs and sustained our supposal which only one pathological notching could be induce in certain lead for a piece of small localized myocardial injury. Experiments made known that ligatured notching could locate all over the whole interval of QRS complex. It increased the distribution at initial segment, if the place of the myocardial injury found the location near endocardium that all so accord with anatomic relation.

According to these results, notching and sluring responses cardiac injure much faster than Q-wave abnormal, R-wave reducing, ST-segment elevating, and T-wave pathological change, so the components only respond a local, slight and early change of heart state but clinical ECGs reflect a larger scale and serious change of state. And that, HFCs are the early information of clinical diagnostic and the information of traditional ECG is used to reflect pathological changes.

In long-term chronic observation, one for raising 63days and another for raising 49 days had got a piece of injury of cicatricial phase and endocardium or front-low wall between epicardium and mid-wall for each after cut sections for microscopic examination. In 2 instances, one was observed and measured days after the initial experiment. At first day of injury, the pathological notching induced in chest lead V2, next day it disappeared and changed into abnormal Q-wave, then it returned back but the Q-wave disappeared again. After several day changing, it become stable and persistence with no change. During the examined days of one dog, the pathological notches were present 5 days after ligature and then they had disappeared completely. During the 5 day period of experiment, all notches in leads Ⅱ, aVR, V3 and V5 changed frequently.

The same regular pattern in other five dogs happened in long-term chronic investigation recently.

Ⅴ. SUMMARY

We have been using with operation to examine model of dogs in order to make sure about injury location and follow the trail of heart state change and record the information much closed nature objective law of heart state.

Small intramural injury were successfully produced in the myocardial wall either formalin injection or ligature of coronary areas 25 dogs. HFCs need to go through

character extraction and pattern recognition in order to get the pathological notching for early diagnosis.

Experimental repeatability indicates that the transition of sluring is much bigger, therefore sluring compared with notching not to useful as a diagnostic criterion but it can be used to indicate the change trend of heart state and might not be used as a parameter standing alone. After induced localized myocardial lesion, sluring generally had no change obviously and abnormal sluring no change either in total, even though its numbers varied a lot.

Usually, computing the number of notching and sluring may be not correct for clinical diagnosis because the number depends on many factors and could not foresee the relation of pathological change, and it only shows that the cardiac physiological state may will change strenuously if the number increases by bits. However, all dog experimental studies could show that first, HFI are very useful for clinical early diagnosis and notches are used to diagnose some heart diseases such as myocardiac ischemia injury and lack oxygen of all kinds because HFC, notching and sluring were caused by a much slight changes (especially sluring) so that notching could be used for early diagnosis of some kind of heart diseases and all numbers of HF components could be forecasted pathological change tendency of heart state and notching has useful value of idiosyncratic, local and global, early and dynamic characteristics for early diagnosis, second, Q-wave abnormal, R-wave reducing and its duration increasing , ST-segment changing and T-wave standing up side down and so on were caused by heart more serious or outmoded pathological changes, that could be used as usual.

Finally, we would like to emphatically point out as follows: 1) the derivative method for drawing HFI data has much better features of simple, good real-time safe and reliable. 2) wavelet also can do well to detect HFECG but real-time feature is not as good as derivative, 3) Both FFT or frequency method have noting to do for dealing with HFCs because it is no any sensitive to it, 4) nonlinear analysis method also is useless for studying HFCs, 5) using dogs as pathological model of heart diseases to study the features of HFI are very useful, and 6) HFI has very useful values of idiosyncratic, local, early and dynamic characteristics for early diagnosis of some heart diseases.

REFERENCE

1. Langner P. H., Jr., The value of high fidelity electrocardiograph Using the cathode ray oscillograph and an expanded time scale. Circulation, 5:249,1952
2. Langner P. H., Jr. 1953, High fidelity electrocardiography: Further studies including the comparative performance of four different electrocardiographs. Am Heart J., 45: 683,.1952
3. Langner P. H., Jr., Further studies in high fidelity electrocardiography: Myocardial infarction, Circulation, 8:905:1953
4. Langner, P. H., Jr. and Geselowitz D.B. Characteristics of the frequency spectrum in the normal electrocardiogram and in subjects following myocardial infarction. Circulation Res., 8:577, 1960
5. Geselowitz D.B., Langner P.H. and Mansure F.T., Further studies on the first derivative of the electrocardiogram including instruments available for clinical use. Am. Heart J., 6: 805, 1962
6. Franke E. K., Braunstein J. R. and Zellner D. C., Study of high frequency components in the electrocardiogram by power spectrum analysis. Circulation Res., 10:870, 1962
7. Flower N.C., Horan L.G., Thomas J.G., Thomas J.R. and Tolleson W.J., The anatomic basis for high frequency components in the electrocardiogram. Circulation, 39:531, 1969
8. Chien I-C.m., Tompkins W.J. and Briller S.A., Computer methods for analyzing the high-frequency electrocardiogram. Med Bio. Eng. Comput . 18: 303, 1980
9. Ge Jiguang and Tompkins W.J., High-frequency ECG feature recognition using a high level language. Biom. Scien. Instrum,. 19: 31,1983
10. Ge Jiguang and Tompkins W.J., High-frequency Electrocardiogram analyzer. IEEE Trans. On Biomedical Engineering. Vol. BME-33: 1137, 1986
11. Ge Jiguang; Dai Jiwang and Xu Yualei, Experimental study of high-frequency electrocardiogram, Proceedings of Ann inter conf of IEEE EMBS, 13: 654, 1991
12. Kyozo Ishikawa and Masayuki Yotsukura, High frequency components in Electrocardiogram. Respiration and circulation, 31:129,1983
13. Zhu Weiping, Zhang Yunfeng, Zhang Chunhua and Tang Lin, The distribution of high-frequency notches of normal human. Shandon Biomedical Engineering, l/2: 4, 1986
14. Ge Jiguang, Xu yuwei and Dai jiwang, Pathological change of dog's high-frequency ECG under acute myocardial injury, Journal of Zhejiang University, 28: 692, 1994
15. Ge Jiguang, The idiosycratic feature of high-frequency cardiac components with acute injury in dog's myocardium, Chinese journal of physical medicine, 18: 179, 1996
16. Ge Jiguang, Dai jiwang and xu yualei, A pathological model study for high-freguency electrocardiogram with coronary after ligature. Journal of Zhejiang university, 31: 81,. 1997
17. Xu qiuping, Ge Jiguang, Xu zheng, Study of high-frequency electrocardiogram in experimental dogs before and after myocardial ischemia, J. of Zhejiang university, 31: 737, 1997
18. Xu qiuping, Zhang, Ge Jiguang, Linear and nonlinear study of heart rate variability related with degree of coronary artery occlusion, Chinese J. of physical medicine, 19: 65, 1997
19. Zhang hui, Ge Jiguang, Yang mingjing and Xu qiuping, Nonlinear dynamics characterization in electrocardiogram, Chinese J. of biomedical engineering, 17: 214, 1998