Further Studies in High Fidelity Electrocardiography: Myocardial Infarction

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High fidelity electrocardiography employing the cathode ray oscillograph with an expanded time scale reveals considerable high frequency notching, slurring, beading, and other peculiarities not seen in the conventional electrocardiographic records on the same individuals. Although some of these cathode ray records contain components whose frequencies are well in excess of 1000 cycles per second, in this paper a frequency analysis will not be reported but rather the electrocardiograms will be presented as patterns with unique detail that is readily apparent even to the casual observer. Using this technic it was found that 14 of 21 individuals with healed myocardial infarction had a greater incidence of obvious high frequency components in their cathode ray electrocardiograms than was found in a series of 60 normal controls. The possible significance of this finding and the need for further study are discussed.

In two previous papers the technic of high fidelity electrocardiography employing a cathode ray oscillograph and an expanded time scale for the more detailed study of electrocardiographic patterns was described and a summary of our findings in normal individuals was presented. The present paper consists of a report of 21 patients with healed myocardial infarction studied by this technic. This group was compared with a control series of 60 apparently healthy individuals free from any past history, symptoms, or signs of cardiovascular disease. Our purpose in studying patients with healed myocardial infarction and residual diagnostic Q waves in their records was to determine whether such patients having clearly documented heart disease also possessed increased high-frequency detail in the record made by the cathode ray oscillograph, using an expanded time scale. In general, the cathode ray oscillograph records of this abnormal group revealed characteristics not seen in our normal group. There was a noticeable or distinct increase in detail as manifested by high frequency notching, slurring and beading, or bizarre patterns in a majority of the abnormal group. The high frequency components of this additional detail were not revealed by the conventional electrocardiogram.

The use of a considerably expanded time scale in electrocardiography which revealed increased detail has been previously reported by Groedel and Reid and Caldwell. However, they did not use a cathode ray oscillograph. Gilford has used a cathode ray oscillograph and a Fairchild camera for recording electrocardiograms. He observed some increased detail in the tracings but concluded after a limited study that it did not contribute significantly to clinical interpretation. However, Gilford did not establish any high frequency criteria for the differentiation of normal and abnormal individuals. Dunn and Rahm have also used a cathode ray oscillograph and an expanded time scale for electrocardiography. They concluded that when compared with a cathode ray oscillograph, the conventional electrocardiographs tested by them appeared to be inadequate for accurate recording and resulted in definite distortion of the electrocardiographic deflections and loss of fine detail. Although Dunn and Rahm were aware of the increased high frequency detail in their cathode ray oscillograph records, they have not yet published any evaluation of this to the best of our knowledge. Kerwin has concluded that the investigation of frequencies as high as 6400 cycles per second and a paper speed of 500 mm. per second are warranted for research. Thus far he has not evaluated the practical significance of these high frequencies in pathologic processes.
Material and Methods

The high fidelity instrument used in this study consisted of a DuMont Cathode Ray Oscilloscope, type 304-H, using the DC amplifier and a specially built preamplifier. The camera was a Westinghouse Oscilloscope Camera, model ph 33671-1, using Kodak Linagraph paper no. 697. The frequency response curve is substantially flat to 1000 cycles per second. The paper speed was approximately 350 mm. per second in most experiments. The amplification was usually regulated in such a manner that the QRS deflection occupied about two-thirds of the diameter of the cathode ray oscillograph fluorescent screen. This resulted in a standardization of from 2 to 6 cm. = 1 mv. depending on the size of the QRS deflection.

Our group of normal controls consisted of 60 employees of the Provident Mutual Life Insurance Company. The age span was fairly evenly distributed from 20 to 65 years. They had received periodic cardiovascular studies in the course of routine health examinations and were known to be in good health. Fifty-four were males and six were females. In all cases the usual six limb leads and precordial leads from V1R to V6 were made on a conventional direct writing electrocardiograph. In all individuals with horizontal hearts and in a majority of others additional leads were made in the third left intercostal space. Sufficient exploration of the chest was always performed to be sure the largest obtainable R waves were recorded from the left precordium. Then the six limb leads and the six precordial leads from V1 to V6 were recorded on the cathode ray oscillograph. In a few cases additional leads were made beyond the routine precordials when necessary to record the largest positive or negative precordial deflection.

The abnormal group consisted of 21 males who had a well documented episode of myocardial infarction from one to nine years ago. All had residual deep Q waves considered to be diagnostic of healed infarction in the conventional electrocardiogram. In addition to the Q waves some of the records showed notching and slurring of low frequency. The ages of the subjects by decades were 2 in the fifth, 11 in the sixth, and 5 in the seventh decades. Three were in the eighth decade, being 70, 71, and 73 years old. All were ambulatory and, except for angina pectoris in 10 individuals, they were feeling fairly well. None had any evidence of congenital, syphilitic, or rheumatic heart disease. None were in congestive failure. The heart was of normal size in 16 and slightly enlarged in 5. These five cases were also receiving digitalis. The blood pressure was within normal range in 17 and from slightly to moderately elevated in 4. The conventional electrocardiogram showed damage of the diaphragmatic wall in 11, of the anterior wall in four, and of both the anterior and diaphragmatic wall in six.

Normal Criteria

In a previous paper high frequency criteria for normal cathode ray oscillograms and examples of normal variations were presented. We will summarize these briefly and bring them up to date. These criteria are not concerned with the low frequency notching and slurring which is obvious even in the conventional electrocardiogram. More than two distinct deformities consisting of either high frequency notching, slurring or marked beading, or a combination of these, was considered in excess of normal variation when these occurred in the following portions of the QRS complexes: (1) in the two-thirds of the QRS deflection farthest from the base line in the three of the six limb leads with the largest amplitude; (2) in the distal two-thirds of the R wave in deflections of the precordial leads to the left of the transitional complex.

The transitional complex as well as complexes to the right of this are frequently deformed in normal individuals. However, this is usually only slight to moderate. Therefore, marked notching, slurring or beading in such records was considered abnormal. Occasionally bizarre patterns, such as flat peaks or nadirs with or without other deformity and waviness of the QRS without definite slurring are observed. In normal individuals this is slight to moderate at most, whereas in some abnormal subjects unusually bizarre patterns of this type were observed, such as illustrated in figure 6. We have been unable to establish criteria for differentiating persons with normal hearts from those with abnormal hearts on the basis of changes in the two or three limb leads of smallest amplitude or the small component of a larger QRS deflection. However, continued studies of small deflections will not be neglected.

In our normal group there was no consistent increase in high frequency detail with advancing age. In fact, some of the most extreme normal variations have occurred in the younger individuals. We have observed no high frequency detail in the T waves so these will not be discussed and will be omitted from all but one of the illustrations to conserve space. The P waves were frequently more notched than
in the conventional electrocardiogram. Thus far we have not made any attempt to evaluate additional detail in the P waves so these will be omitted from all but one illustration.

Fig. 1. The first R wave illustrates the influence of 60-cycle interference. There is a resultant moderate increase in beading. This extreme degree of 60-cycle interference was artificially induced and is never encountered normally. The second R wave shows the result of extreme induced muscle tremor. When such a degree of tremor occurs spontaneously the tracing is considered uninterpretable for high frequency detail. Additional fragments of the base line are mounted below the R waves to conserve space.

Fig. 2. This tracing was run at a much slower paper speed (130 mm. per second) than any of the others illustrated. The base line is quiet, yet there is marked beading of the R downstroke which has a consistently repetitive pattern in all R waves. This is lead II from an individual with healed diaphragmatic wall infarction. The conventional electrocardiogram mounted above the cathode ray oscillogram showed no detail in the R waves.

RESULTS
Of the 21 individuals with healed myocardial infarction, 14 had a degree of high frequency detail which we felt was unquestionably in excess of that observed in any of our 60 normal controls. In five individuals with healed infarction there was increased high frequency detail, but it was questionable whether it exceeded that observed in a few “extreme normals.” These individuals were classified as borderline. In one of the abnormal group the interference from muscle tremor made it impossible to evaluate high frequency detail. And in one individual who had had an episode of infarction seven years before and whose tracing showed marked left axis deviation and a residual QS in lead III there was only a slight degree of high frequency detail which we would classify as within normal limits. He has been well since his acute detail and free from angina pectoris. Of the 14 individuals with excessive high frequency detail, 9 were having angina pectoris. Of the five borderline and one within normal limits only one had angina pectoris.

Leads from 10 patients were chosen to illustrate “abnormal” degrees of high frequency detail. However, let us first consider artefacts. Figure 1 illustrates the two main sources of these. The first R wave in figure 1 shows in-
more troublesome artefact is that due to muscle tremor. The second R wave in figure 1 shows muscle tremor induced by having the subject raise his head off the table. In the presence of marked muscle tremor high frequency detail cannot be evaluated, and even in the presence of slight to moderate irregularities of the base line due to tremor the high

Fig. 3. This shows marked beading of the peak and early downstroke in lead II in a patient with anterior and diaphragmatic wall infarctions. This is not seen in the conventional electrocardiogram mounted below the cathode ray oscilloscope. Four QRS complexes of the oscilloscope are mounted to show that the beading is consistently repetitive.

Fig. 4. Two QRS complexes illustrate marked beading of R_{II} in a subject with infarction of the diaphragmatic wall. The conventional electrocardiogram mounted below the oscilloscope shows only a barely perceptible low frequency notch on the R upstroke and a slight notch on the R downstroke. All 12 cathode ray oscilloscope records in this subject showed abnormal increase of the high frequency detail.

duced 60 cycle interference. In our experience the slight amount of 60 cycle interference which occasionally occurs under normal operating conditions causes no significant distortion of the QRS other than slight beading. Another

Fig. 5. The upper two complexes show marked variation in the speed of the photographic trace with excessive beading of the upper half of R_{II} in a subject with infarction of the diaphragmatic wall. The conventional electrocardiogram shows only a Q_{II} and one low frequency notch near peak of R. The lower pair of records are aV_{F}. In aV_{F} the R upstroke is so fast it fails to record in this cathode ray oscilloscope. The P-QRS-T from the conventional electrocardiogram are mounted with their respective cathode ray oscilloscope counterparts.

frequency detail must be interpreted with caution. Slight muscle tremor is fairly common in the limb leads but unusual in the precordial V leads.

Figures 2, 3, 4 and 5 illustrate beading which we believe is in excess of normal variation. In each instance the subject had a healed diaphragmatic wall infarction with deep Q waves in leads aV_{F} and III. In figure 2 the base line is quiet, yet there is marked beading which
has a consistently repetitive pattern in the R downstroke of lead II. Figure 3 shows marked beading of the peak and early R downstroke. This has been repeatedly and consistently recorded in this individual who has survived episodes of both anterior and diaphragmatic wall infarction and now has severe angina. His chest leads were also markedly deformed. For a detailed description of figures 4 and 5 the reader is referred to the legends.

![Figure 6](image)

**Fig. 6.** This shows bizarre flattening and deformity of the top of R_{11} in a subject with infarction of the diaphragmatic wall. Two deflections of the cathode ray oscillogram are shown; one immediately below the other. The conventional electrocardiogram mounted below the oscillogram shows a slightly broad R peak.

Figure 6 shows an unusually bizarre broad peak of R_{11} in a subject with healed diaphragmatic wall infarction.

Figures 7 and 8 illustrate examples of high frequency detail definitely in excess of normal variation in individuals with anterior wall damage. In figure 7 there is excessive notching and beading in the QS in V_{3} and the QRS in V_{4}. In figure 8 the peaks of V_{4} and V_{5} are distinctly deformed. None of our 60 normals has such a distinct deformity in the peak of any predominantly positive precordial record. The diagnosis in the conventional electrocardiogram was diaphragmatic wall damage based on deep Q waves in leads II, aVF, and III.

Yet the cathode ray oscillogram revealed abnormalities in precordial leads also.

Figure 9 illustrates serial change in V_{4} after a second episode of myocardial infarction. This individual had typical Q waves in leads II, aVF and III in June, 1951 but then the precordial leads were normal. On Sept. 19, 1951 he had another episode of myocardial infarction. One year later a cathode ray oscillogram revealed the striking serial change in V_{4} illustrated in figure 9. The conventional electrocardiogram revealed normal precordial leads, whereas all the precordial leads in the oscillogram from V_{4} to V_{5} and at levels two inches above and below these electrode positions revealed records with deformities near the peak of R consisting of high frequency notching and beading.

In addition to the 21 individuals with diagnostic Q waves in the conventional records, four additional instances of clinically diagnosed coronary disease seem worthy of comment. We obtained a cathode ray oscillograph record without unusual high frequency detail from a 53 year old individual with angina pectoris and a history of healed myocardial infarction. His conventional electrocardiogram is also normal now but a Master two-step test had been performed and was positive. His blood pressure was 170/100 which may or may not be significant. An additional case of definite angina pectoris in an individual with both normal conventional electrocardiogram and cathode ray oscillograph record, except for
minimal S-T depression, was observed. This patient was also hypertensive, the blood pressure being 210/110. On the other hand, another patient was observed with a clear-cut episode of myocardial infarction without diagnostic severe angina. This record is deformed far in excess of the two other records of right bundle branch block which we obtained from two healthy individuals without other history, symptoms, or signs of cardiovascular disease.

![Image 8](image_url)

**Fig. 8.** This shows deformities in V₃, V₄, and V₅. We have not observed this degree of deformity of the peak of V₄ and V₅ in any normal subject. The conventional electrocardiogram not mounted here revealed only the one gross low frequency notch seen in V₅.

![Image 9](image_url)

**Fig. 9.** The first QRS complex is lead V₁ recorded in June 1951. This deflection is perfectly smooth. The next two are successive QRS complexes from a strip of V₁ recorded in May 1953, following recovery from myocardial infarction. Marked notching is now present. The conventional electrocardiogram shows only damage of the diaphragmatic wall. See text for further details.

Q waves in the routine leads; in this patient lead II was grossly deformed in the oscillogram but not significantly so in the direct writer as illustrated in figure 10. Figure 11 illustrates a record showing right bundle branch block in a patient with healed myocardial infarction and

**DISCUSSION**

The purpose of this study was to determine whether individuals clinically diagnosed as having definite coronary disease had records made with a cathode ray oscillograph showing increased high frequency detail not revealed
in the conventional electrocardiogram. We felt that if this should prove to be the case, it would justify embarking upon a much larger undertaking to determine whether increased high frequency detail occurring in individuals with normal conventional electrocardiograms was of prognostic or diagnostic significance. Since this latter type of study would require observation of a fairly large number of individuals over a period of time, it seemed advisable before starting such an extensive project to examine examples of obvious cardiac disease to obtain some idea of what might be expected.

While our experience is too limited to establish criteria for differentiation of borderline normal and abnormal records, or indeed to assert positively that there exist distinct high-fidelity criteria, we felt that, at this point, it was worth while to give a brief summary of our findings and to illustrate some of the more unusual wave forms found in individuals with coronary disease. In this latter group there is definitely increased high frequency detail, but whether its diagnostic value is worth the increased expense and time involved remains to be determined. It would have been very fortunate if all normal individuals had smooth regular records and all subjects with abnormal hearts gave records which were obviously notched or slurred. However, such a clear-cut differentiation did not always prove to be the case, so the problem of abnormal high frequency detail is quantitative as well as qualitative with some possible overlapping between the two groups.* Criteria for the range of normal variation require further investigation. But we feel that so far in our two small series the differences have been significant in a majority of cases, and if extension of these studies continues to show the same results then the differences between the two groups may prove to be of diagnostic and/or prognostic significance.

Fig. 10. This shows lead II in a subject described in the text. There is marked deformity of the peak in R11 whereas the conventional electrocardiogram shows only a slight slurring at the peak of the R wave.

The increased detail in high fidelity electrocardiography, such as high frequency notching, slurring, beading and peculiar wave forms is not seen in the conventional electrocardiogram for three reasons. First and foremost, is the low frequency response of the usual electrocardiograph such as the direct writer, string galvanometer, and low frequency mirror galvanometer. The second reason is the low amplification of the tracings. An amplification

Fig. 11. This shows unusual deformity of V2 and V3 in a subject with right bundle branch block and longstanding coronary disease. While some deformity is also revealed in the conventional record it is much less detailed.

* This discussion is concerned only with differences in high frequency or other details not visible in the conventional electrocardiogram. In all 21 cases of healed myocardial infarction there were obvious diagnostic Q waves, and in some cases there was also low frequency notching and slurring, in both conventional and cathode ray records. These Q waves and other low frequency phenomena which were obviously present in the conventional electrocardiogram are not the subject of this discussion.
of such degree that 1 mv. gives a deflection of from 2 to 6 cm. may be necessary to reveal properly the high frequency detail. The third reason is the slow paper speed of the usual electrocardiograph.

The type of analysis of records used in this paper differs from the vector approach in that we have emphasized pattern detail. On the other hand, we have considered this detail significant in the limb leads only when it occurs in the three leads of largest amplitude, which of course are relatively collinear with the long axis of the QRS loop in the frontal plane. If two of the six limb leads are used for recording a loop, then all the detail found in any of the limb leads must also be present in this loop, provided it is sufficiently enlarged or magnified and is not interrupted with time signals. However, we believe this detail will be more difficult to evaluate from the loop. Furthermore, certain detail found in the precordial leads may not be present in loops recorded by distant electrodes. This problem has not been studied by us and we believe to do it adequately a "panoramic viewer" employing a cathode ray oscillograph would have to be used.

In our group of 60 normal individuals there was no general tendency to increased high frequency detail with age. In fact, we found the greatest normal variation in younger people. Of course, our sample is too small to give an adequate picture.

Whatever the mechanism of the high frequency detail during depolarization, it is not appreciable during the slower process of repolarization because we have not observed any high frequency detail in the T waves. In fact, we have observed abnormal high frequency detail in the cathode ray oscillogram of the QRS complex without any S-T or T-wave abnormalities in the conventional electrocardiogram; and on the other hand, S-T and T-wave changes in the conventional electrocardiogram may occur without high frequency detail in the QRS complex recorded by the cathode ray oscillograph.

Since we have found increased high frequency detail in cases of healed myocardial infarction, and since Zoll, Wessler and Blumgart have shown that multiple myocardial infarction is the most common autopsy finding in angina pectoris, we might speculate that a majority of individuals with angina pectoris would ultimately have increased high frequency detail in tracings made with a cathode ray oscillograph. Whether this occurs frequently in the presence of a perfectly normal conventional record remains to be determined. It is possible that in some patients with early angina, who have not had significant permanent heart muscle damage, there might be S-T or T-wave changes with no increased high frequency detail in the electrocardiogram since the mechanism of these two phenomena would seem to be different.

Several possibilities for future studies to determine the value of this increased high frequency detail suggest themselves. The most interesting one would be to determine whether significantly increased detail occurs in the cathode ray oscillograph record of asymptomatic individuals who have normal conventional tracings, and if so, whether it is a precursor of clinically manifest coronary disease. Such a finding would be helpful in identifying coronary disease in its incipiency. Second, we have observed serial change in cathode ray oscillograms while the conventional tracing remained apparently unchanged. (See figure 9.) This could be of diagnostic value. And third, since the tracings made with the cathode ray oscillograph reveal much more detail, they might prove to be a valuable adjunct in assessing the degree of tissue damage or recovery. The great problem is to determine the time at which significant, high frequency notching, beading, and other high frequency detail begin to occur in the course of coronary disease. Do these occur before obvious low frequency abnormalities appear in the conventional electrocardiogram, or are the high frequency components later phenomena which appear concurrently with or after diagnostically significant Q waves have already made their appearance in a majority of cases? This study, which we hope to pursue, would require a long term follow-up of cases of angina and other types of individuals suspected of having coronary disease.
Summary and Conclusion

Of 21 individuals with healed myocardial infarction and residual diagnostic deep Q waves, 14 had much greater high frequency detail and bizarre patterns in their cathode ray oscillograph records than did normal individuals, 6 were borderline, and only 1 was within normal limits for high frequency detail. The possible significance of this finding is discussed. Further studies are warranted to evaluate the role of high fidelity electrocardiography in the diagnosis and prognosis of heart disease.

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Sumario Español

Electrocardiografía de alta fidelidad empleando el oscilógrafo de rayo cátodo con escala de tiempo expandida, reveló identaduras de alta frecuencia considerables, slurring, molduras convexas, y otras peculiaridades no vistas en trazados electrocardiográficos convencionales en los mismos individuos. Aunque algunos de los trazados de rayo cátodo tienen componentes con frecuencias en exceso de 1000 ciclos por segundo, en este informe no se discutirá un análisis de la frecuencia, pero en lugar los electrocardiogramas se presentaran como patrones con singular detalle que aparecerá obvio hasta el observador casual. Usando esta técnica se encontró que en 14 de 21 individuos con infartos del miocardio cicatrizados tenían una incidencia de componentes obvios de alta frecuencia en los electrocardiogramas de rayo cátodo mayor que en una serie de 60 controles normales. El posible significado de este hallazgo y la necesidad de más investigación se discuten.

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