FREQUENCY ANALYSIS OF THE ECG BEFORE AND DURING VENTRICULAR FIBRILLATION

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Frequency analysis of cardiac electrograms of dogs with ventricular fibrillation (VF) during complete cardiopulmonary bypass and coronary perfusion showed a power spectrum with a peak around 12 Hz and its higher harmonics, suggesting more organization than generally assumed. As a next step to see whether this conclusion could be of clinical use, we estimated in the same way power spectra of VF in patients. Pseudo three-dimensional displays of these "consecutive" spectra clearly showed a distinction between the ECG of a beating heart and the ECG during VF; both could be clearly distinguished from the noise of "loose" electrodes. During VF the power spectrum shows a peak around 6 Hz plus its higher harmonics. The spectrum did not change in character or basic frequency during relatively long periods (45 sec's).

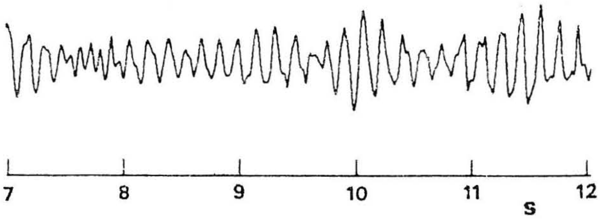


fig. 1: ECG of a dog with VF during cardiopulmonary bypass and coronary perfusion (plotted after A-D conversion at 100 Hz); time axis in seconds after the start of VF.

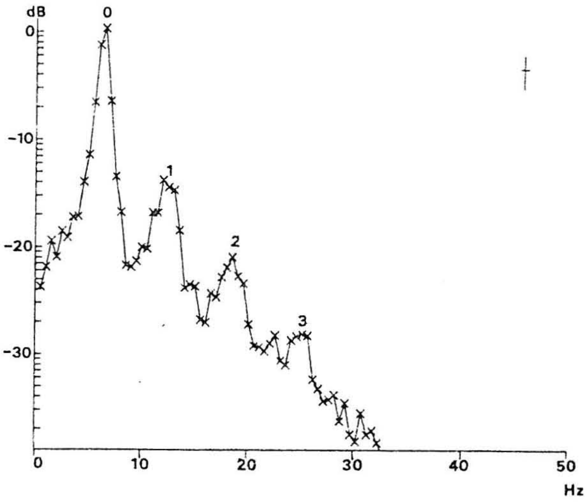


fig. 2: Autopower spectrum of VF (see fig. 1) averaged over 10 blocks; the numbers indicate the basic frequency and the higher harmonics; the vertical line in the upper right corner represents the 95% confidence interval.

INTRODUCTION

The frequency content of the ECG of patients during ventricular fibrillation (VF) has been investigated directly by Agizim (1), Nygårds (2) and Hulting (3) and indirectly (by filtering) by Kuo (4) in order to design a reliable automated ECG monitoring system that will detect VF quickly without mistakes. On the other hand signal analysis of VF in dogs was performed by us (5) in order to get a more quantitative description of the ECG during VF than the official WHO/ISFC Task Force (6) definition: "an irregular, disorganized electrical activity of atria or ventricles... In ventricular fibrillation QRS and T waves can no longer be identified. The recorded deflections continuously change in shape, magnitude and direction." Contrary to this definition is the fact that the majority of the ECG signals during VF is characterized by a power spectrum with narrow, equidistant peaks, see Nygårds (2), Hulting (3) and Herbschleb (5). Figure 1 shows a typical example of VF in an anesthetized dog during complete cardiopulmonary bypass and coronary perfusion. The characteristic power spectrum is depicted in figure 2 (see (5) for details). Different forms of induced VF in dogs could be described by one model with different sets of parameters, Herbschleb (7). As a first step to see whether our model is also valid in humans, we applied our signal analysis methods to VF in patients.

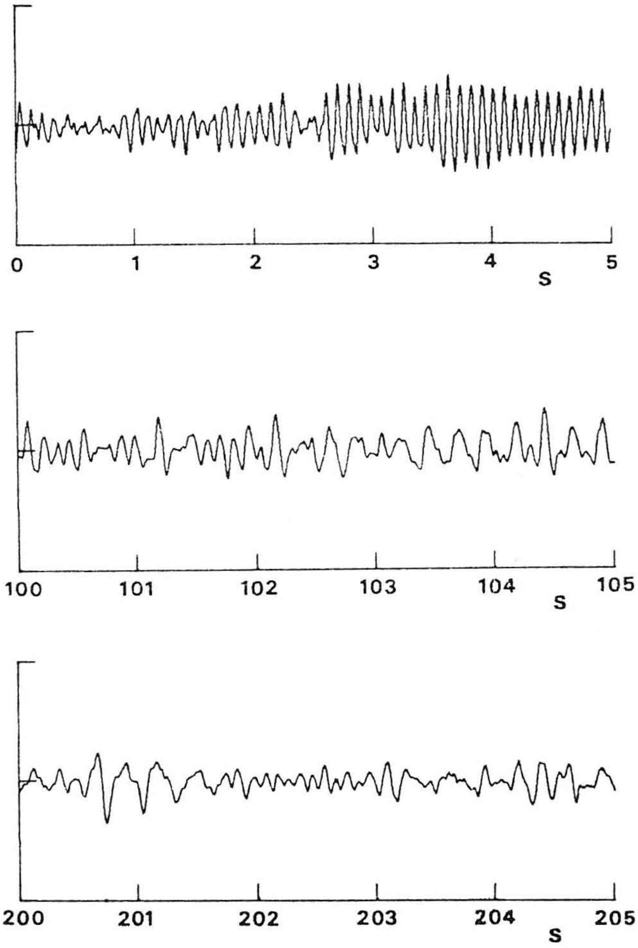


fig. 3: ECG of a dog with VF without coronary perfusion; see also fig. 1.

METHODS

The ECG signals were recorded on analog tape via conventional electrodes. Prior to analysis the analog signals were converted to digital values at a sampling frequency of 100 Hz and stored on magnetic tape. See figures 1,3,6 and 9 for plotted examples of the digitized signals. The converted signal was divided in blocks of 200 sample points, representing an actual length of 2 seconds. These blocks were subjected to Fourier transformation.
In order to see what changes would occur in course of time, an estimation of the autopower spectrum was made by calculating a moving average of 10 consecutive blocks of transforms.
Using the DISSPLA graphics software package a pseudo three-dimensional impression of the moving average of the power spectrum is shown in figures 4,7 and 10. Contour lines of these three-dimensional images were drawn at 5 dB levels. The contour charts were coloured by hand; the higher the power, the darker the shade (see figures 5,8 and 11).

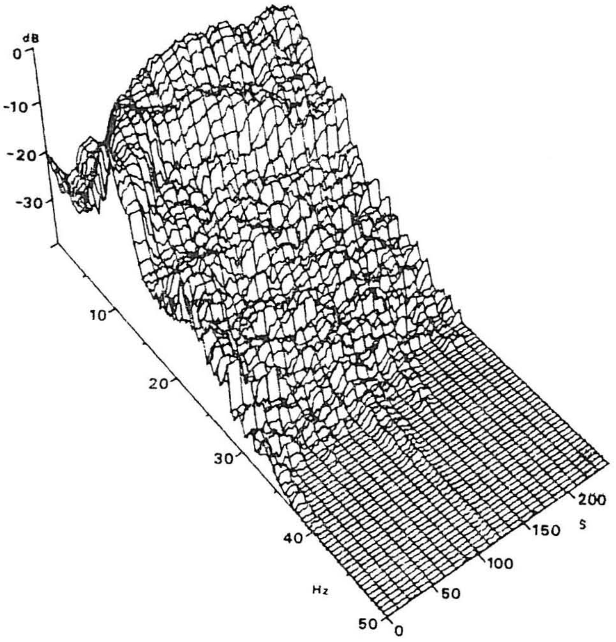


fig. 4: pseudo three-dimensional display of the power spectrum of VF (see fig. 3) in course of time.

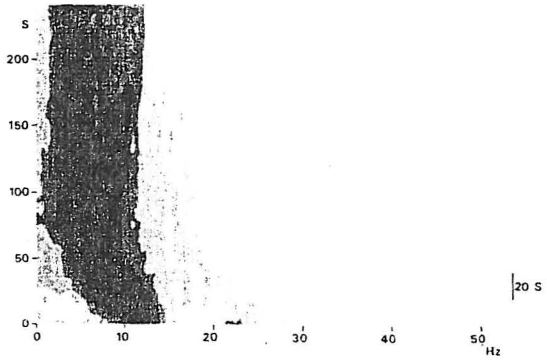


fig. 5: contour chart of fig. 4; contour lines are drawn at 5 dB intervals; a darker shade indicates a higher power; the vertical line at the right side indicates the moving average interval in forward direction.

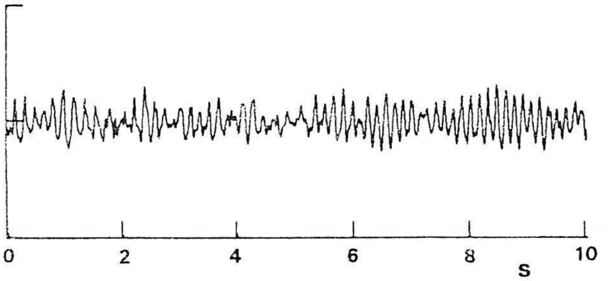


fig. 6: ECG of a patient with VF; see also fig. 1.

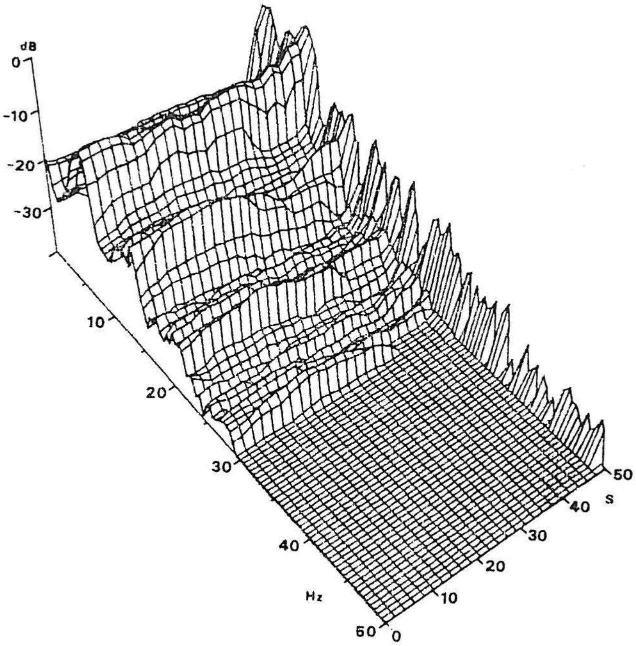
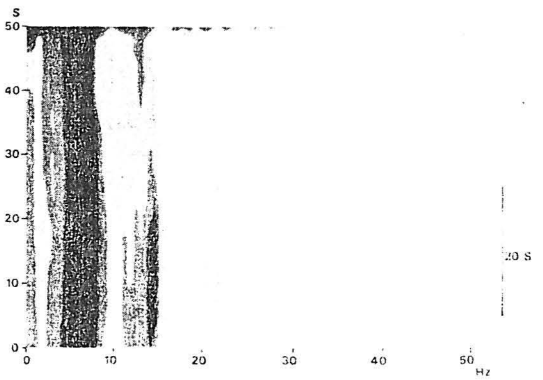


fig.7: pseudo three-dimensional display of the power spectrum of VF (see fig. 6) in course of time.



fi.g 8: contour chart of fig. 7; see explanation of fig. 5.

RESULTS

Dogs

Our previous studies (5) of induced VF during cardiopulmonary bypass and coronary perfusion suggested some organization during VF. As a next step we analyzed the ECG during induced VF in two healthy, intact dogs. In both cases the following pattern was seen: fast and fairly regular VF in the first ten seconds, followed by a slowing down and increasing irregularity (fig. 3). The fibrillation starts with a basic frequency of 11 Hz and a higher harmonic of 22 Hz, then slows down to 4.5 Hz, remains rather stable and regular between 60 and 140 seconds after the onset of VF as indicated by the clear higher harmonic around 9 Hz and becomes slower and more irregular after 150 seconds (fig. 4 and 5). Especially the three-dimensional representation (fig. 4) clearly indicates the decrease in amplitude of the higher harmonic.

Patients

Up till now 9 occurrences of VF in 5 coronary care patients became available for analysis. In general, if there is a sufficiently long period of VF (> 20 sec's), the power spectrum shows a peak at the basic frequency of fibrillation plus at least one higher harmonic. If the heart is fairly regularly beating, normally or in tachycardia, the largest peak in the power spectrum corresponds to the mean heart rate and no higher harmonics of this peak are present (fig. 10 and 11). The power spectrum of noise of a loose electrode has no resemblance whatsoever to the power spectrum of VF. A typical example is shown in fig. 7 and 8. No conclusions can be drawn with respect to correlation between clinical data and type or form of power spectrum or with respect to reliability, because of this small number. We only want to show and comment two examples of VF in patients.

The first example is VF of 45 sec's duration, which arose without premonitoring arrhythmia in a 59 yr old man with a recent inferior-posterior infarction. A part of the ECG after A-D conversion is shown in fig. 6. The power spectrum (fig.7 and 8) indicates clearly, that the basic fibrillation frequency remains constant during the whole duration of VF. Up to three higher harmonics are seen in the first 30 sec's, afterwards the power of the higher harmonics diminishes, indicative of a more irregular signal (compare to fig.4 and 5). Prior to defibrillation the recording electrode got disconnected, which caused the noise spectrum at the end of the recording period.

The second example consists of tachycardia and VF in a 76 yr old man with an old anterior-septal infarction. Fig. 9 shows the transition from tachycardia to VF. The power spectrum (fig. 10 and 11) during tachycardia contains only one clear peak at the heart rate frequency (1.9 Hz or 114 beats/min). At the onset of VF the power spectrum changes abruptly into the typical VF spectrum with peaks at 4.3, 8.6, 13.0, 17.3, 21.6, 25.9 and 30.2 Hz. Curiously enough the contour chart (fig. 11) still indicates the presence of the original peak of 1.9 Hz during VF.

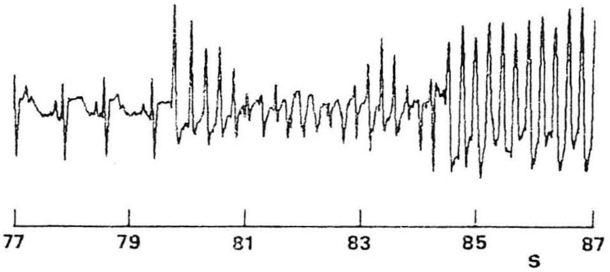


fig. 9: ECG of a patient with tachycardia and VF (see also fig. 1); time axis in seconds after arbitrary start of recording.

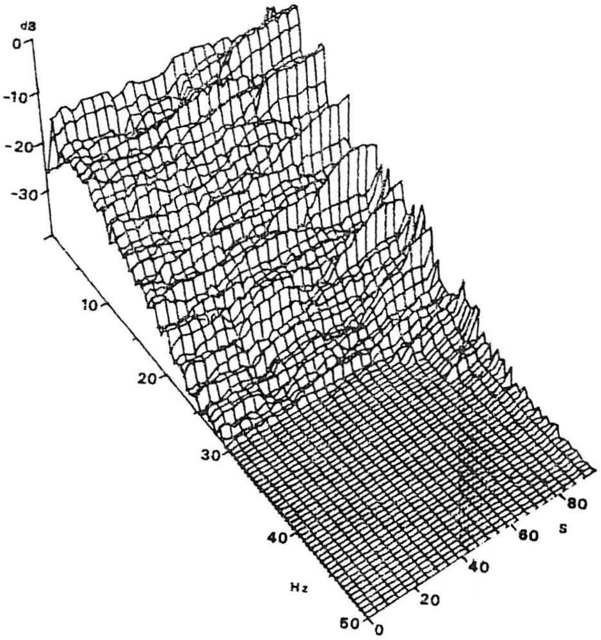


fig. 10: pseudo three-dimensional display of the power spectrum of an ECG recording (see fig. 9).

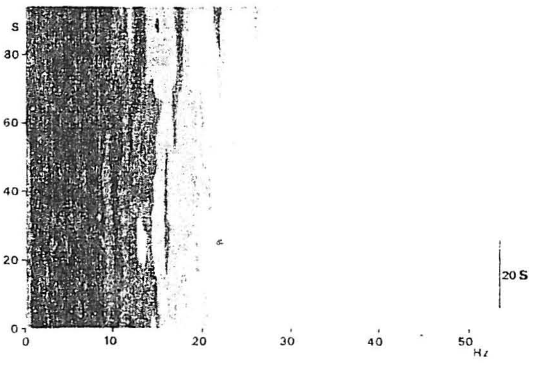


fig. 11: contour chart of fig. 10; see explanation of fig. 5.

CONCLUSION

The time course of the power spectrum of the ECG seems a sensitive tool to detect ventricular fibrillation and to investigate different types of VF. Our results in patients confirm our previous results in dogs ((5) and (7)), that the electrical activity in the ventricles during VF is a much more organized phenomenon than previously thought of (6).

Acknowledgement

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