Physician Interpretation and Quantitative Measures of Electrocardiographic Ventricular Fibrillation Waveform

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Abstract

Objectives. The characteristics of the ventricular fibrillation (VF) waveform may influence treatment decisions and the likelihood of therapeutic success. However, assessment of VF as being fine or coarse and the distinction between fine VF and asystole are largely subjective. The authors sought to determine the level of agreement among physicians for interpretation of varying VF waveforms, and to compare these subjective interpretations with quantitative measures. **Methods.** Six-second segments of waveform from LIFEPAK 300 units were collected. Fifty segments, including 45 VF and five ventricular tachycardia (VT) distracters, were graphed to simulate rhythm strips. These waveforms were quantitatively described using scaling exponent, root-mean-squared amplitude, and centroid frequency. Thirty-two emergency medicine residents were asked to interpret the arrhythmias as VT, "coarse" VF, "fine" VF, or asystole. Their responses were compared with the qantitative measures. Interphysician agreement was assessed with the kappa statistic. **Results.** One thousand four hundred forty interpretations were analyzed. There was fair agreement between physicians about the classification of arrhythmias ($\kappa = 0.39$). Mean values associated with coarse VF, fine VF, and asystole differed in all three quantitative measure categories. The decision whether to defibrillate was highly correlated with the distinction between VF and asystole (Pearson chi-square = 1,170.40, df = 1, p[two-sided] < 0.001). **Conclusions.** With only fair agreement on the threshold of fine VF and asystole, defibrillation decisions are largely subjective and caregiver-specific. These data suggest that quantitative measures of the VF waveform could augment the current standard of subjective classification of VF by emergency care providers.
Key words: cardiac arrest; heart arrest; ventricular fibrillation; asystole; waveform; scaling exponent; amplitude; centroid frequency.

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Automated analysis of electrocardiographic (ECG) signals is well established. Discrimination of different rhythms is sufficiently reliable that automatic internal defibrillators, that can detect rhythms for which electrical defibrillation or cardioversion is indicated, are routinely implanted in patients. Furthermore, automated external defibrillators (AEDs) are now being deployed for use by laypersons on unconscious subjects.[1] However, the qualitative discrimination of unorganized rhythms such as ventricular fibrillation (VF) from organized supraventricular rhythms may ignore valuable information in the ECG waveform, which may have implications for the prognosis of treatment decisions.[2]

The morphology of the VF waveform has been associated with different physiological states of the heart. In animals, the amplitude of VF declines over time.[3–5] Furthermore, the frequency characteristics of induced VF follow a predictable pattern during ischemia.[6–12] In

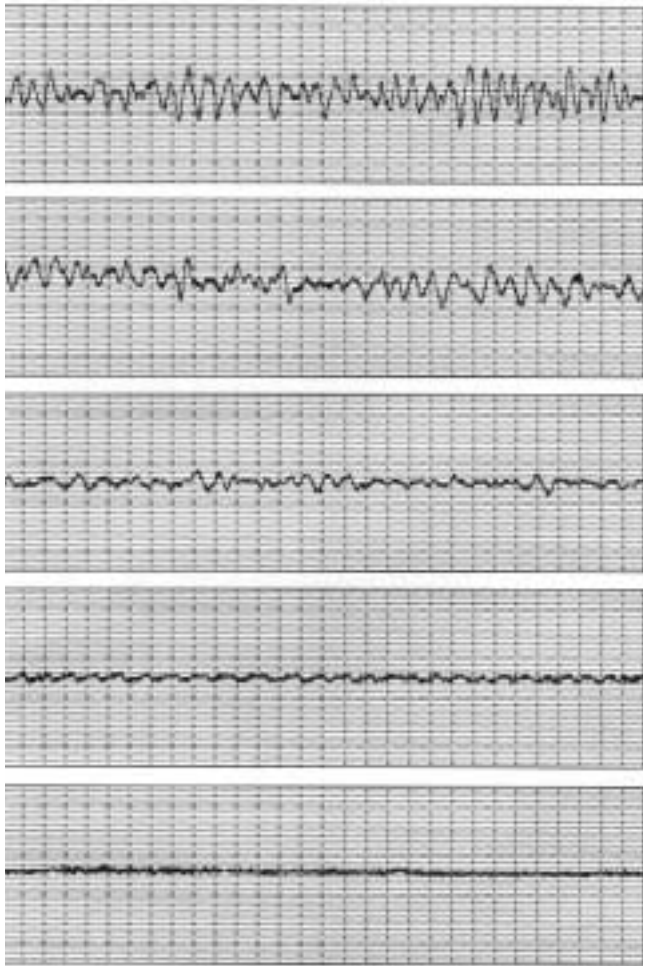

Figure 1. Example of the variability found within the segments of waveform. Five panels of waveform represent the visible changes from coarse ventricular fibrillation to asystole.

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TABLE 1. Guidelines for Classifying Kappa

κ Value	Level of Agreement
<0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

humans, fewer systematic data are available. However, common clinical experience also suggests that VF amplitude declines over time and lower dominant frequencies of VF are associated with more prolonged ischemia.[2,12,13] Deciding whether to defibrillate VF is dependent on caregivers' making the distinction between VF and asystole. The probability of successful outcome may be related to the physiological state of the heart. Because the decrement of ECG amplitude from coarse VF to asystole is continuous, distinguishing fine VF from asystole is arbitrary.[14,15] This discretionary distinction is seen clinically and may affect patient treatment and outcome.[16] Therefore, describing the quality of the VF waveform may augment research and clinical care by stratifying patients into different prognostic groups and by more precisely defining asystole.

The widespread distribution of AEDs and advisory defibrillators suggests that machine-based quantitative ECG measures may soon be available in routine clinical practice. Rhythm interpretations by paramedics and other health care providers have shown to be highly variable.[17–19] However, the extent to which quantitative measures should influence caregiver judgment is unknown. Therefore, we sought to assess the level of agreement between different physicians for classifying VF as coarse, fine, or asystole and for deciding whether to defibrillate. As a secondary aim, we compared the physicians' interpretations with three different ECG measures—amplitude, centroid frequency, and scaling exponent. We hypothesized that quantitative measures derived from the VF waveform could augment the physician discriminations between coarse VF, fine VF, and asystole.

METHODS

This study was approved by the Biomedical Institutional Review Board of the University of Pittsburgh. Thirty-two resident physicians from the University of Pittsburgh Affiliated Residency in Emergency Medicine program gave voluntary informed consent to participate in this study. The subjects included residents in their first, second, and third

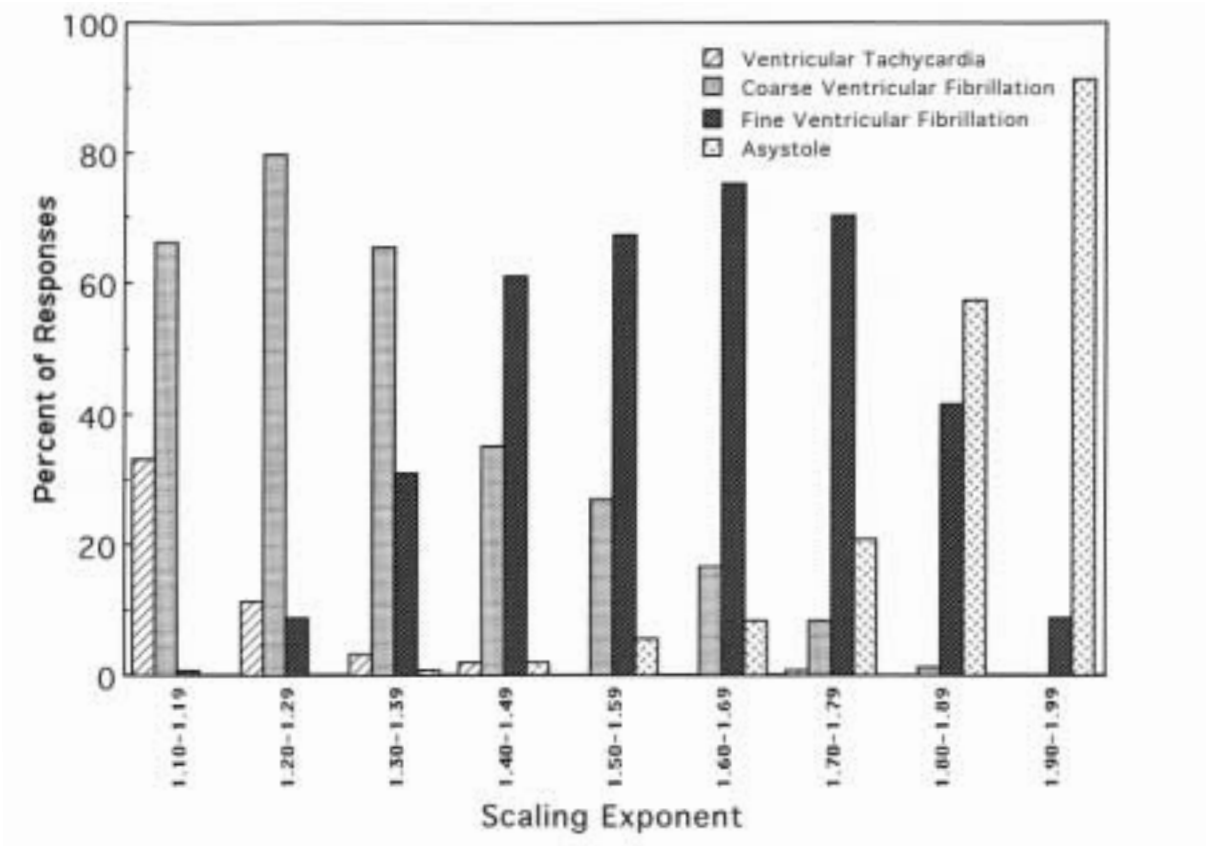

FIGURE 2. Physician classification of ventricular fibrillation (VF) waveform versus scaling exponent. The percentage of respondents classifying rhythms strips as ventricular tachycardia (VT), coarse VF, fine VF, or asystole is plotted versus the values of the scaling exponent. Five strips were rated by 32 physicians within each bin.

TABLE 2. Quantitative Measures of Ventricular Fibrillation (VF) Waveform*

	Scaling Exponent	Amplitude (mV)	Centroid Frequency (Hz)
Coarse VF	1.333 ± 0.166 (1.318, 1.348)	0.160 ± 0.085 (0.152, 0.168)	4.845 ± 0.804 (4.772, 4.917)
Fine VF	1.610 ± 0.170 (1.596, 1.624)	0.073 ± 0.026 (0.071, 0.075)	5.230 ± 1.191 (5.132, 5.327)
Asystole	1.870 ± 0.118 (1.856, 1.883)	0.062 ± 0.022 (0.059, 0.064)	6.732 ± 2.025 (6.500, 6.965)
Defibrillate	1.464 ± 0.226 (1.451, 1.478)	0.122 ± 0.083 (0.117, 0.127)	5.055 ± 1.066 (4.993, 5.118)
Intravenous medication and continue cardiopulmonary resuscitation	1.845 ± 0.146 (1.828, 1.861)	0.063 ± 0.025 (0.060, 0.066)	6.582 ± 2.007 (6.359, 6.804)

*Mean ± standard deviation (95% confidence interval).

years. At the time of the study, they were all currently certified in American Heart Association Advanced Cardiac Life Support (ACLS).

We conducted a prospective study in which subjects independently interpreted ECG strips in random order. These subjects were presented 45 segments of VF and five ventricular tachycardia (VT) distracters. Electrocardiographic data were obtained from AED recordings from a police first-responder program, as has been previously described in full.[20–22] The data were recorded on analog tapes by a LIFEPAK 300 AED (Physio-Control, Redmond, WA) and then digitized at 400 points/second with an analog/digital converter and software (PowerLab, AD Instruments, Castle Hill, Australia). Quantitative descriptors of the VF segments were calculated. These descriptors have been described in detail in previous publications and included the scaling exponent,[23] a mathematical measure of the amount of two-dimensional space the waveform fills; root-mean-square (RMS) amplitude, the average vertical deflection of the waveform; and centroid frequency,[2] a value derived from a fast Fourier transform, which is related to the peak-to-peak appearance. Epochs were selected such that they included the entire range of scaling exponents from 1.1 to 2.0. Scaling exponent values between 1.0 and 1.1 had not been encountered in our human VF recordings. Six-second epochs of waveform were graphed to simulate rhythm strips with a scale of 25 mm/second and 10 mm/mV. Figure 1 is representative of the visual variability of waveforms in our study.

The 50 strips were assembled in a randomized order

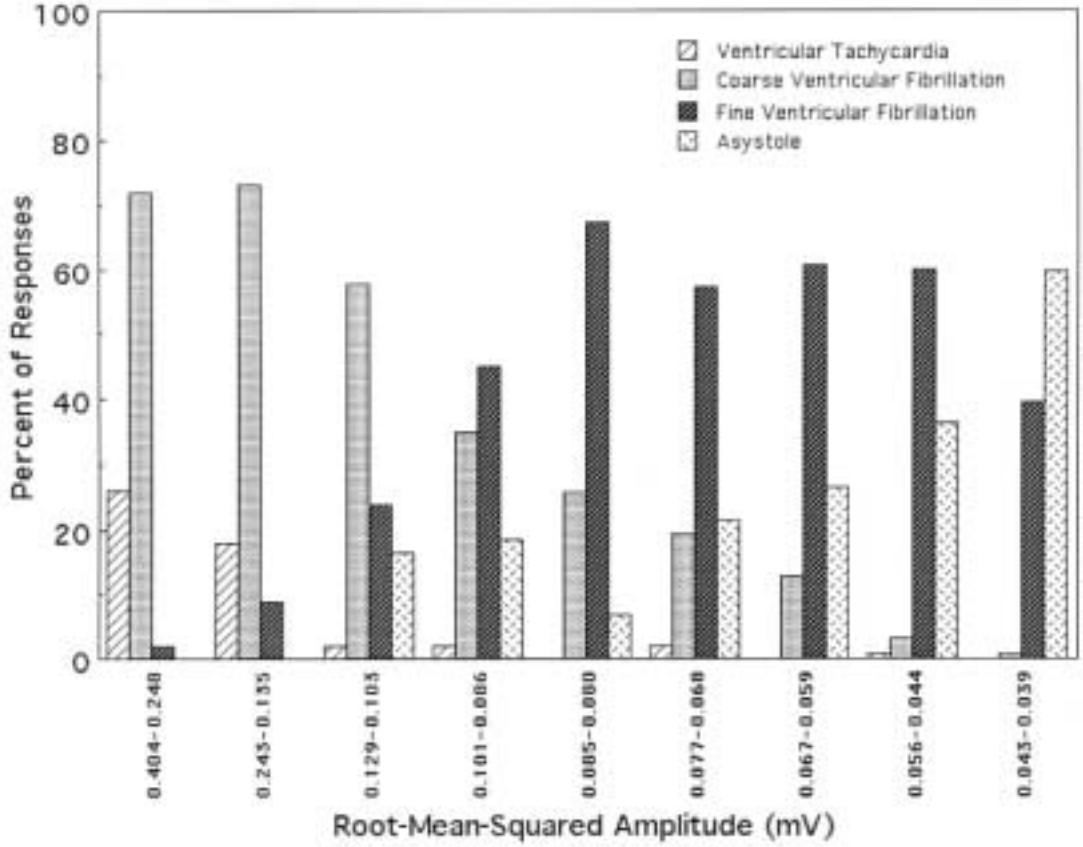

FIGURE 3. Physician classification of ventricular fibrillation (VF) waveform versus root-mean-squared (RMS) amplitude. The percentage of respondents classifying rhythms strips as ventricular tachycardia (VT), coarse VF, fine VF, or asystole is plotted versus the values of the amplitude. Five strips were rated by 32 physicians within each bin.

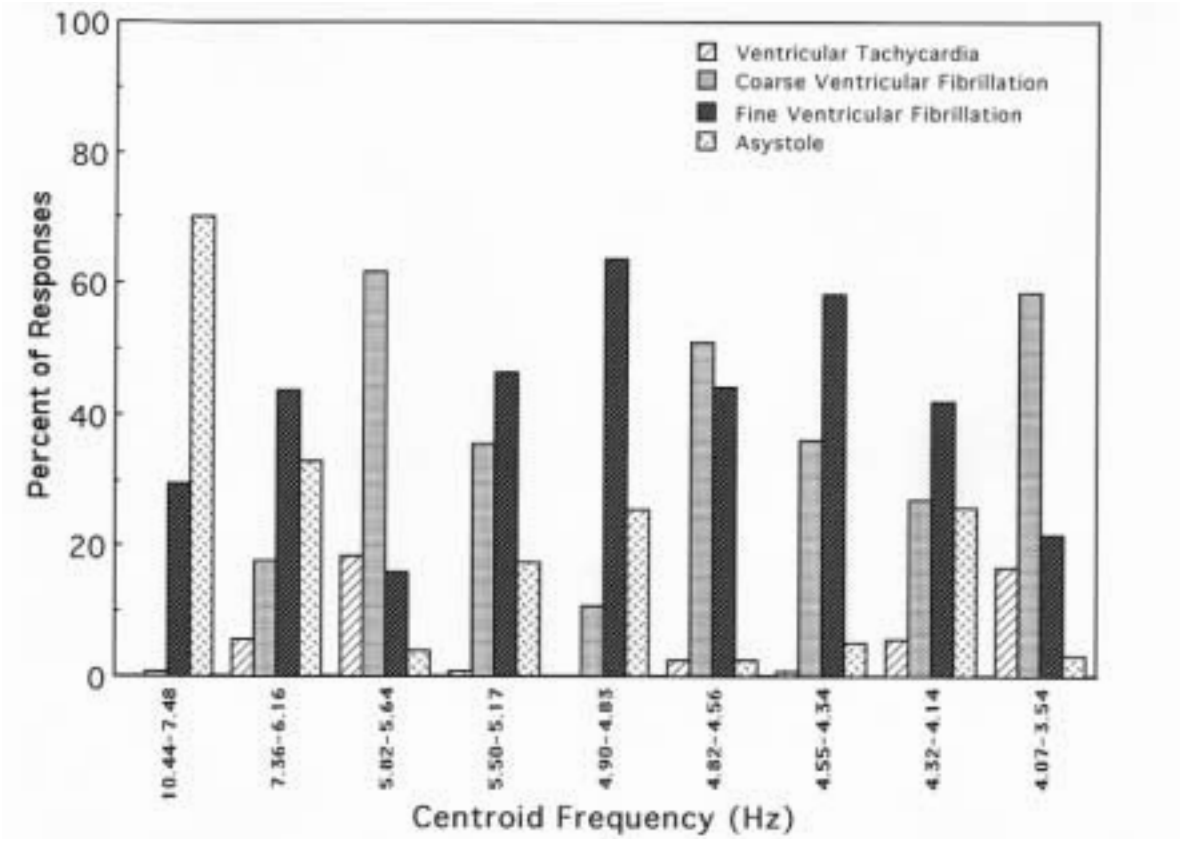

FIGURE 4. Physician classification of ventricular fibrillation (VF) waveform versus centroid frequency. The percentage of respondents classifying rhythms strips as ventricular tachycardia (VT), coarse VF, fine VF, or asystole is plotted versus the values of the centroid frequency. Five strips were rated by 32 physicians within each bin.

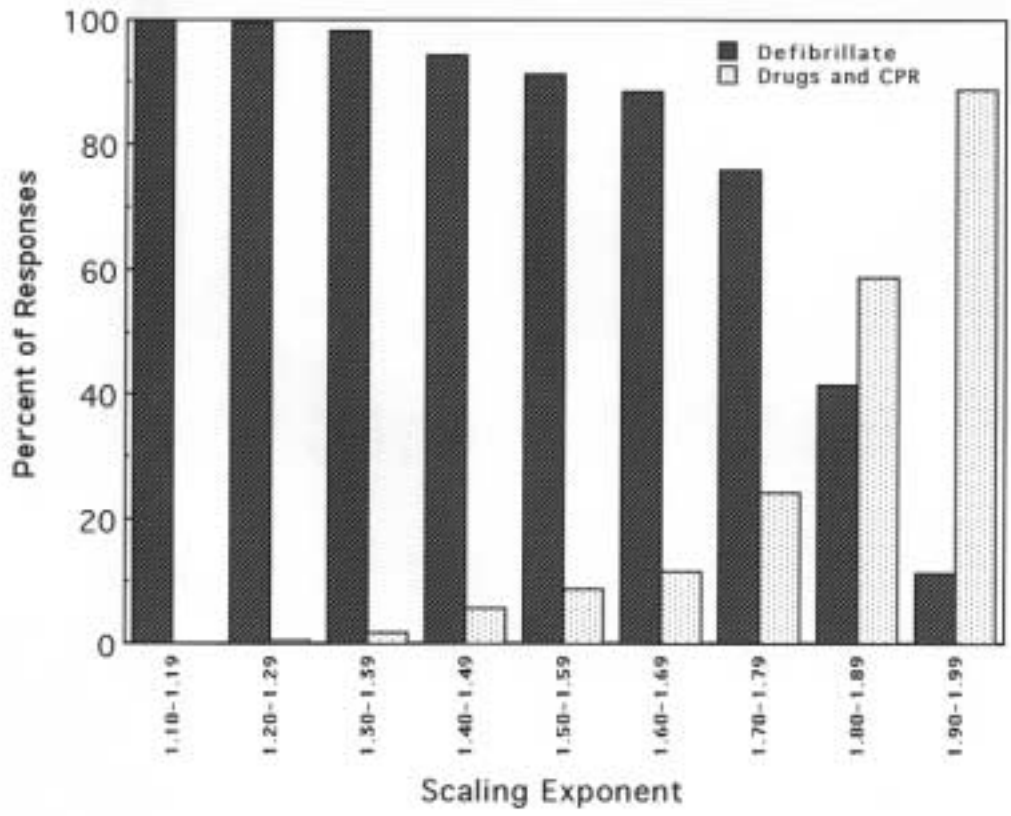

FIGURE 5. Recommended treatment versus scaling exponent. The percentage of respondents recommending immediate defibrillation or cardioplmonary resuscitation (CPR)/drug administration is plotted versus the values of the scaling exponent.

into booklets and handed out to each physician. The participants were separated so as to reduce the possibility of influencing each other's responses. They were not permitted to consult with each other, and there was no time limit for their completing the task. Each page contained one ECG strip and the following script: "Your patient is adult, has no pulse, and CPR is ongoing. The patient is intubated and has good IV access. The rhythm you see is the same in all leads, and your equipment is functioning properly. This is: VT, coarse VF, fine VF, or asystole? Your next action is: defibrillate, or give IV medication and continue CPR?"

Interrater reliability of our samples was described with kappa statistics. We found variability in the literature as to the interpretation of the level of agreement when using kappa; our analysis was based on the criteria found in Table 1.[24] Mean values of the scaling exponent, amplitude, and centroid frequency for segments classified as coarse VF, fine VF, and asystole were determined. In order to determine whether the quantitative measures were different for the various rhythm classifications, mean values were compared by analysis of variance (ANOVA) with a significance level of $p < 0.05$. A correlational chi-square test was performed to examine the relation between classifying a segment of waveform as VF or asystole and making a treatment decision. Analyses were conducted with SAS (version 6.12, SAS Institute Inc., Cary, NC) and SPSS (version 6.1.1, SPSS Inc., Chicago, IL).

Results

With 32 raters interpreting 45 segments of VF waveform, there were a total of 1,440 classifications. Of these, 79 were categorized as VT, 473 were categorized as coarse VF, 577 were categorized as fine VF, and 294 were categorized as asystole. Several answers were missed in the questionnaires (1.2%); thus, interrater agreement statistics were based on completed booklets from 29 raters. All other observations utilized answers from each of the 32 physicians.

There was only fair agreement between physicians in classifying VF. The kappa statistic for overall interrater reliability showed fair reproducibility ($\kappa = 0.39$). The agreement on asystole was moderate ($\kappa = 0.56$); whereas, on coarse and fine VF it was fair ($\kappa = 0.39$ and 0.32). Agreement was fair ($\kappa = 0.40$) for all VF when coarse and fine VF were combined, post-hoc, into a single classification. Reducing classifications to only three categories (VT, VF, and asystole) led to a moderate overall agreement ($\kappa = 0.44$). Physician agreement to defibrillate had an overall κ value of 0.49, indicating moderate reproducibility for treatment decisions.

The 45 segments of waveform ranged from 1.11 to 1.98 in scaling exponent, 0.04 to 0.40 mV in amplitude,

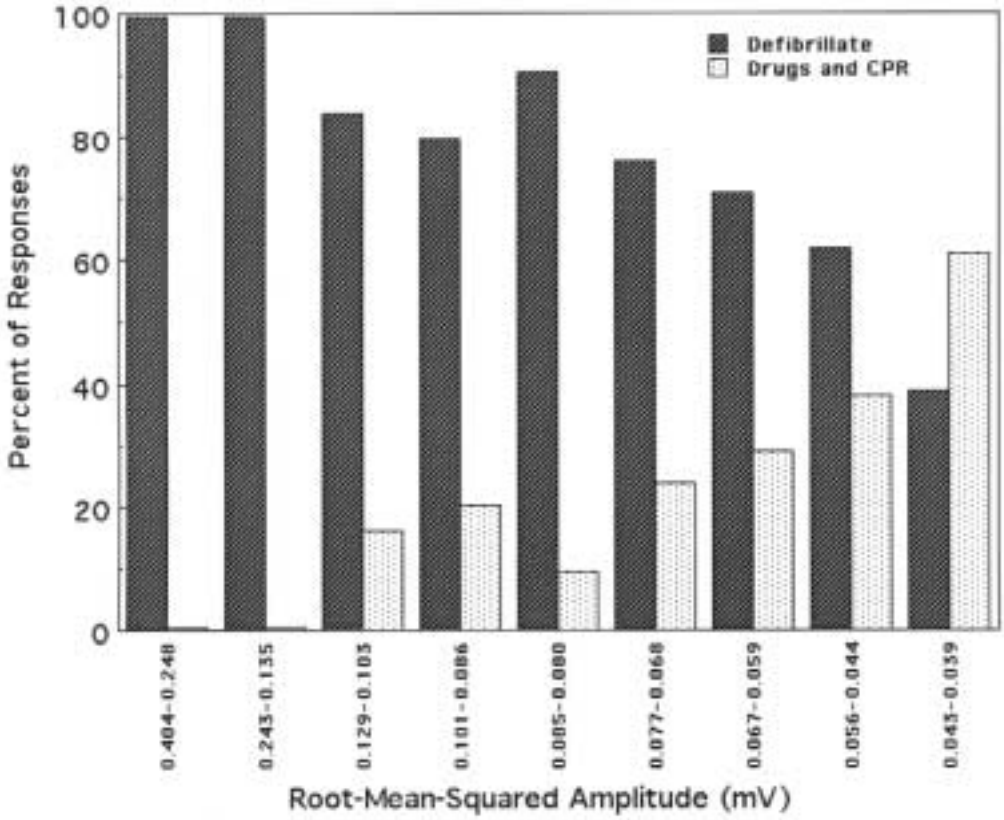

Figure 6. Recommended treatment versus root-mean-squared (RMS) amplitude. The percentage of respondents recommending immediate defibrillation or cardiopulmonary resuscitation (CPR)/drug administration is plotted versus the values of the RMS amplitude.

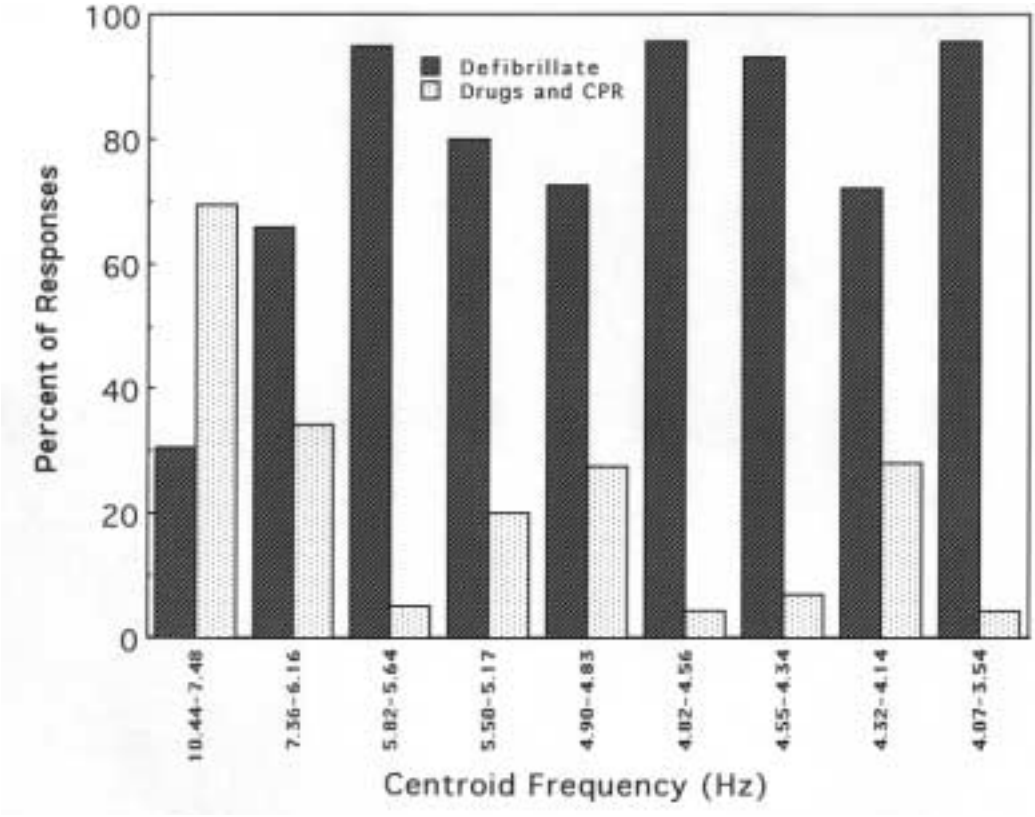

FIGURE 7. Recommended treatment versus centroid frequency. The percentage of respondents recommending immediate defibrillation or cardiopulmonary resuscitation (CPR)/drug administration is plotted versus the values of the centroid frequency.

and 3.54 to 10.44 Hz in centroid frequency. Mean values were 1.55 ± 0.27 for the scaling exponent, 0.11 ± 0.01 mV for amplitude, and 5.40 ± 1.50 Hz for centroid frequency. Using each of the 1,423 separate responses, mean values of coarse VF, fine VF, and asystole differed in the scaling exponent ($p[F = 1{,}069.88, df = 2, 1{,}344] < 0.001$), amplitude ($p[F = 433.12, df = 2, 1{,}344] < 0.001$), and centroid frequency ($p[F = 197.23, df = 2, 1{,}344] < 0.001$) (Table 2). Decisions to defibrillate were highly correlated with the distinction between VF and asystole (Pearson chi-square = 1,170.40, df = 1, p[two-sided] < 0.001).

The relationship between interpretation and quantitative measures are presented in Figures 2–4. The relationship between quantitative measures and treatment decisions are presented in Figures 5–7.

DISCUSSION

This study determined that interrater agreement among physicians for classification of VF as coarse and fine was only fair. For extremes of waveform morphology (Fig. 2, scaling exponent >1.9), interrater agreement by physicians about waveform was better. However, for VF waveforms with intermediate values of amplitude, centroid frequency, and scaling exponent, large variability was observed for rhythm interpretation. Thus, quantitative measures provide greater precision in classifying VF waveform, and may assist clinicians in classification for treatment decisions or research.

There is no clear cutoff between fine VF and asystole. In animals with induced VF, amplitude declines and scaling exponent increases continuously with time. In the present study, the definition of asystole as an ECG amplitude (<100 μV)[15] would classify many cases that physicians identified as fine VF, as asystole (Fig. 3). Automated external defibrillators use multitep algorithms to classify the electrical activity of the heart. In one study, the threshold amplitude for recognizing asystole varied widely between devices.[25] In contrast, a high value of the scaling exponent was closely associated with classification of the rhythm as asystole (Fig. 2). Using amplitude measures alone as the criterion for treatment may not be as effective as the scaling exponent when accounting for the physician agreement about cases of asystole.

The optimal treatment of early VF may differ from the optimal treatment for prolonged VF.[4,13,26–30] While immediate defibrillation has been suggested for all VF,[31] reperfusion and reoxygenation of the heart prior to defibrillation may improve resuscitation after prolonged ischemia.[13,26,27,32–38] Failed defibrillation attempts should be avoided since they are known to be deleterious to the heart and other surrounding tissues.[5,15,26,36,38–47] Therefore, the ability to distinguish

VF that has a high probability of responding to defibrillation from VF that has a low likelihood of success may have implications for immediate therapy.

Interestingly, physicians chose to defibrillate immediately most cases identified as fine VF. The quantitative measures for these cases are associated with a low likelihood of successful defibrillation within this same data set.[48] Thus, the use of quantitative measures could augment treatment decisions.

Although our waveform segments had an even distribution over the full range of scaling exponent values, a limitation to our analysis was many segments had a low RMS amplitude. This could lead to an increase in ambiguous interpretations and thus decrease our kappa values. Our study investigated one small sample within the health care field. It is therefore not possible to generalize our findings to all caregivers. However, with the fact that these emergency residents were trained in ACLS by the same community training center and were part of the same residency training program, homogeneity should bias the study for increased agreement. We speculate that future studies with more heterogeneous samples would find less robust agreement.

CONCLUSIONS

There was only fair interrater agreement between physicians about the classification of VF waveform. Treatment decisions are normally made on the distinction of VF from asystole. The subjectivity of waveform classification could be circumvented by the use of quantitative measures of waveform morphology. Quantitative ECG may improve precision in the selection of immediate therapy.

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