S U D D E N D E A T H

Medical Grand Rounds

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"Tis a vile thing to die, my gracious
lord, When men are unprepared, and
look not for it."

Shakespeare
Richard III, scene iii, act II
(1592)

From infancy to the twilight years of life, the fear of sudden death looms as a menacing ogre over all of our lives. This fear compels us to plan for our families, and is a principle reason for the gigantic life insurance industry, which does much of its merchandising using the fear of sudden death. Sudden death is a tragic occurrence and is used by authors, playwrites, and screenwriters to entangle us emotionally in their tales of tragedy. This sudden death takes many forms, including traumatic injuries, both accidental and purposeful, poisoning, gastrointestinal hemorrhage, subarrachnoid hemorrhage, cerebral hemorrhage, cerebral vascular accidents, aspiration of food, and heart diseases among many others (2).

Sudden death has been defined by the World Health Organization as death within 24 hours of the onset of illness or injury (3). However, for cardiac causes definitions of instantaneous death or death within one hour of the onset of symptoms may be more applicable.

Schwartz and Walsh (4) have analyzed the causes of sudden death from their pathologic series in adults. They have found many etiologies as shown in Table I.

Table I - Principle Conditions Associated with Sudden Death in Adults (2,4)

Cardiovascular
- Atherosclerotic Heart Disease
- Cardiomyopathy
- Rheumatic heart disease
- Bacterial endocarditis
- Myocarditis
- Ruptured aortic aneurysm
- Dissecting aortic aneurysm
- Coronary embolism
- Aortic stenosis
- Pulmonic stenosis
- Congenital heart disease
- Cardiac tamponade
- Barlow's syndrome
- Pulmonary hypertension

Respiratory
- Pulmonary thromboembolism
- Pneumonias
- Acute or chronic cor pulmonale
- Asthma

Table 1 Cont'd.

Bilateral midline fixation of the cricoarytenoid joint
Cafe coronary

Central Nervous System

Intracerebral hemorrhage
Subarachnoid hemorrhage
Meningitis
Encephalomyelitis

Gastrointestinal

Gastrointestinal hemorrhage
Peritonitis associated with perforated peptic ulcer
Alcoholism
Acute fatty liver
Cirrhosis

Other

Trauma
Poisoning and drug reactions
Fulminating infections, including meningococemia
Amniotic embolism
Fat embolism
Myxedema
Amyloidosis
Hemochromatosis
Endocrine dysfunction
Leukemia

As can be seen there are many etiologies of sudden death in adults from pathologic series. In the 20-45 year range the relative incidence of these with sudden death from natural causes is shown in Table II (5).

Table II - Percentage Distribution of Causes of Death from Natural Causes in Young Adults Between 20 and 45 years of age (5)

	Percent
Circulatory system	38%
Central Nervous System	22%
Respiratory System	18%
Gastrointestinal System	13%
Urinary Tract	4%
Miscellaneous	5%

In older age patients the incidence of circulatory and central nervous system cases of sudden death increase remarkably. Hence it is good to remember that sudden death has many etiologies other than cardiovascular.

Jude (6) has pointed out that cardiac arrest can occur from either cardiac arrhythmias, decreased myocardial function, decreased coronary perfusion, or decreased cardiac output as shown in Figure 1.

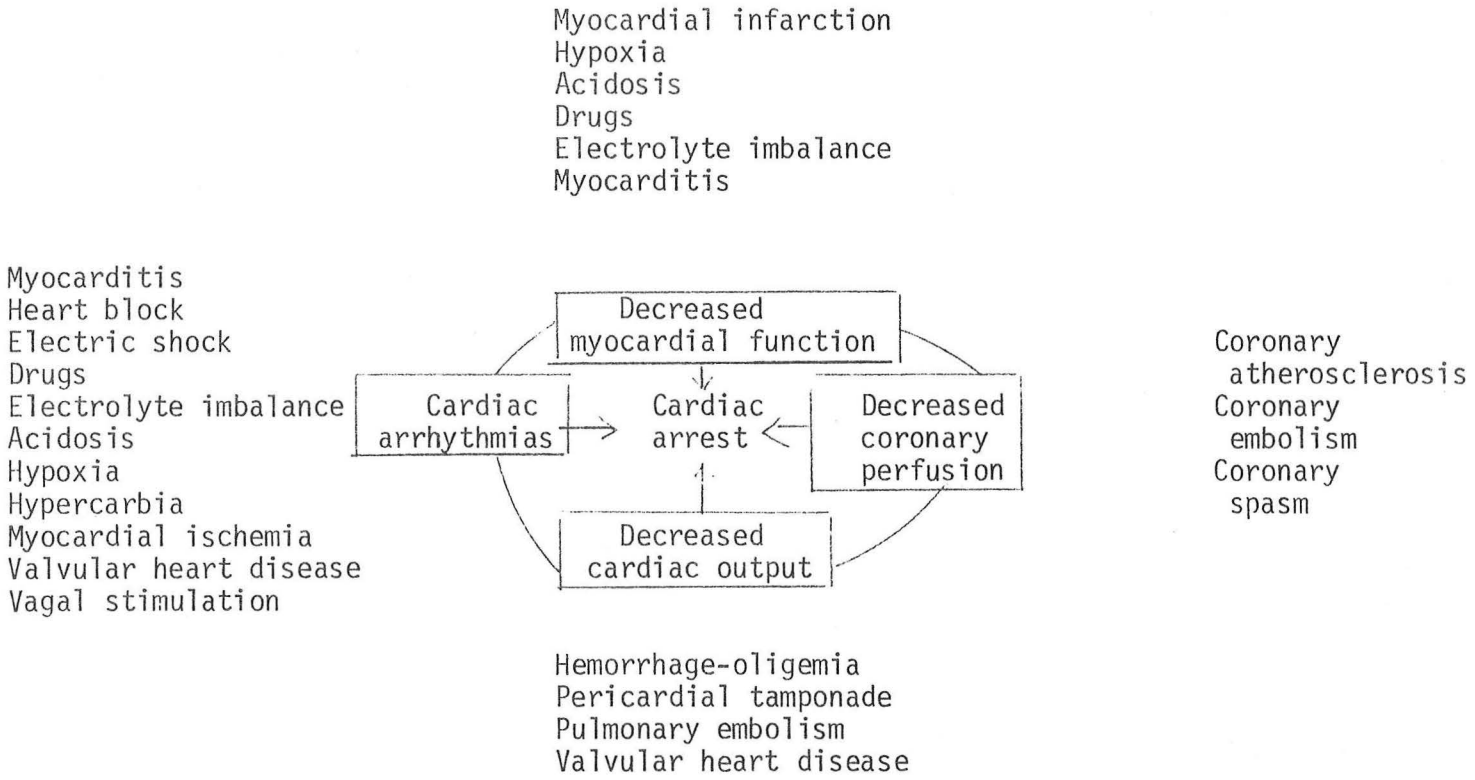


Figure 1. The cardiac arrest circle with four interrelated ultimate factors leading to cardiac arrest (6)

Jude has also pointed out that therapy needs to be aimed at the etiologic problems as well as general resuscitative measures as shown in Figure 2.

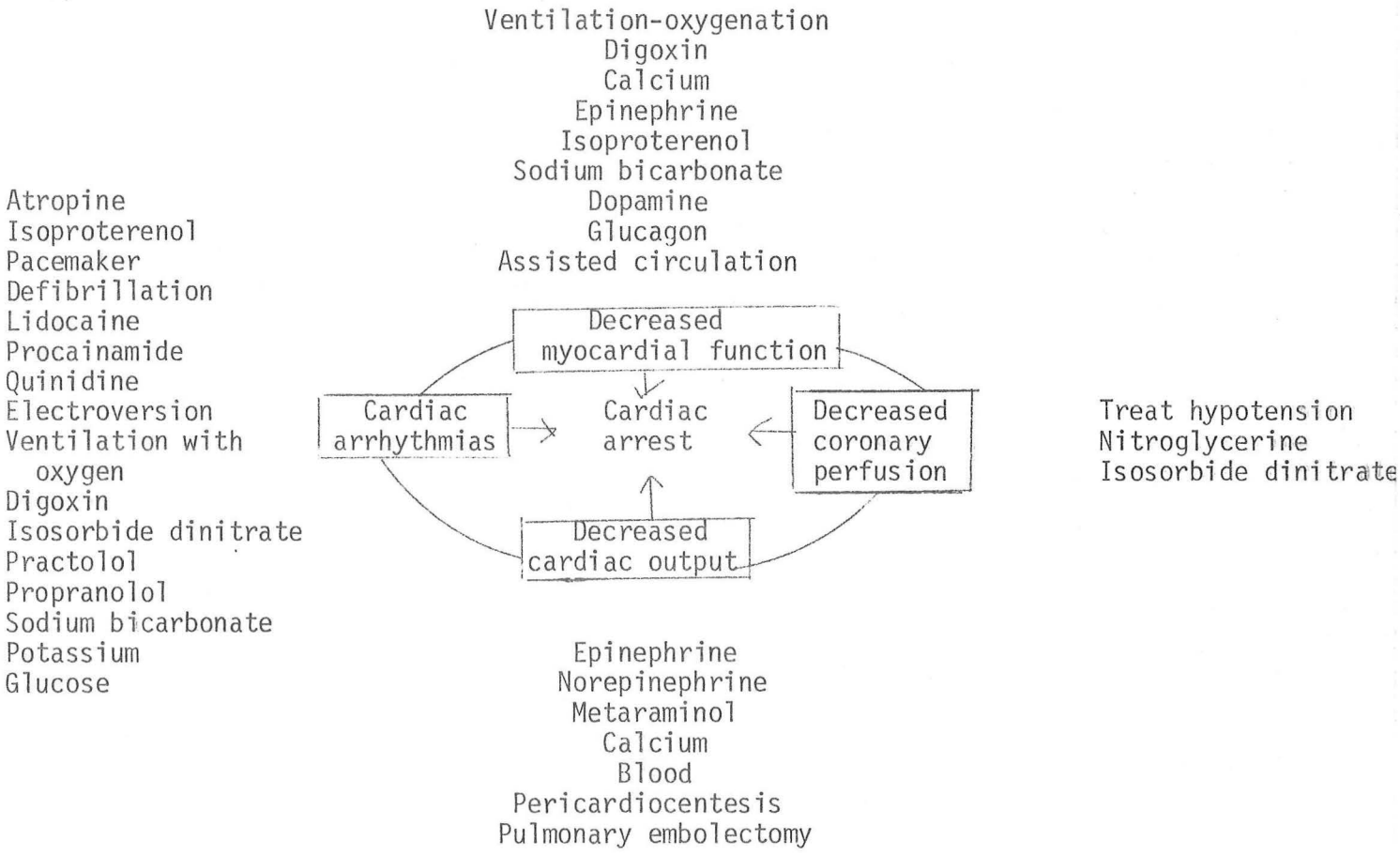


Figure 2. Treatments directed at each ultimate factor in the development of cardiac arrest (6).

For the remainder of this discussion we shall be limited to a discussion of sudden cardiac death and ignore the extra cardiac causes.

Sudden cardiac death can be divided into three major syndromes:

1) Sudden death due to acute myocardial infarction

2) Sudden death due to angina pectoris or ischemia but not infarction

3) Sudden death without infarction or ischemia

Each of these syndromes have different etiologies, different prognoses, and different therapies. Of the 997,766 deaths per year due to coronary artery disease (7), 40 - 75% occur either

instantaneously or within one hour of the onset of symptoms (8). Sixty percent of these deaths occur in the prehospital phase (9). Friedman et al (10) have tried to time the duration of symptoms prior to death as shown in Table III.

Table III. Duration from onset of acute symptoms until death. (10)

Duration category	Cases in each category	
	No.	%
1. "Instantaneous" or < 1 min	49	22.9
2. 1 min to 1 hr	26	12.2
3. < 1 hr but uncertain if < one min	37	17.3
4. 1 to 24 hrs	44	20.6
5. < 24 hrs, otherwise uncertain	28	13.1
6. < 24 hrs, but otherwise uncertain, except was not < 1 min	13	6.1
7. Uncertain if > or < 24 hrs, but not < 1 min	15	7.0
8. Uncertain if < or > 24 hrs, but not > 1 hr	2	0.9
Subtotals		
Clearly < 1 hr (1-3)	112	52.3
Clearly < 24 hrs (1-6)	197	92.1
Possibly 24 hrs or greater (7-8)	17	7.9
Total	214	100.0

Friedman obtained these data from in depth interviews of witnesses and family of 214 males who had previously had risk factors screening in the Kaiser-Permanente Medical Care Plan in California. It is clear that 52.3% of these patients had symptoms for less than 1 hour and 22.9% of these patients had instantaneous sudden death.

Epidemiology

The two best studies for epidemiology of sudden death are the Tecumseh study (11) and the retrospective study of Friedman et al (12) which will be reviewed in depth.

From the Tecumseh study (11) the incidence of sudden death by age is shown in Table IV.

Table IV. Sudden Death by Age at Initial Examination in Tecumseh, Michigan (1959-1965) (11)

Age	Number examined	Sudden Deaths No.	%	6 year incidence of SCD per 1,000 population
30-39	1381	3	6.7%	2
40-49	941	6	13.3%	6
50-59	658	8	17.8%	12
60-69	374	13	28.9%	35
70+	289	15	33.3%	52
Total	3643	45	100%	12

Hence, the incidence of sudden cardiac death (SCD) is greatly increased by age. It is important to note that 40% of the sudden cardiac deaths occurred before the age of 60.

Pre-existant cardiovascular disease or diabetes mellitus greatly increased the risk of sudden cardiac death as shown in Table V (12).

Table V. Incidence of Sudden Death Among Persons 30 years of Age or Older, with Cardiovascular Disease or Diabetes in the Tecumseh Population (1959-1965) (11)

Clinical Diagnosis	No. sudden deaths	No. observed at initial exam.	6 year incidence per 1000 population
Coronary artery disease	18	108	166.7
Diabetes mellitus	8	85	94.1
Hypertension	6	67	89.5
None of the above conditions	17	3,387	5.0

Hence pre-existant coronary artery disease, diabetes mellitus, and hypertension greatly increased the risks of subsequent sudden death just as these conditions greatly increase the risks of myocardial infarction.

The Tecumseh study also revealed that a number of precedent ECG abnormalities also increased the risk of subsequent sudden death as shown in Table VI (11).

Table VI. Relationship of Selected antecedent ECG abnormalities to incidence of Sudden Death in the Tecumseh Population (30 years of age or older) (11).

ECG Finding	No. Sudden Death	No. observed in total population	6 year incidence per 1,000 population
Bilateral bundle branch blocks	3	4	750.0
Left bundle branch blocks	5	18	277.0
Old myocardial infarction	5	26	192.0
Ventricular premature beats	10	165	61.0
Left ventricular hypertrophy	6	124	48.0
First degree A-V block	3	100	30.0
Normal ECG	7	2,700	2.6

Friedman (12) analyzed in detail groups of patients, with instantaneous cardiac death (< 1 minute), sudden cardiac death (1 minute - 24 hours) and instantaneous and sudden non-cardiac deaths. Behavioral patterns and habits are shown in Table VII.

Table VII. Behavior Pattern of Instantaneous and Sudden Death Subjects (12)

	Instantaneous Cardiac Deaths	Sudden Cardiac Deaths	Instantaneous and Sudden Noncardiac Deaths
Number of cases	27	37	16
Average age	54	53	56
Average height	69	69	69
Average weight	164	171	171
Behavior pattern *			
Type A	24	29	6
Type B	1	2	7
Undetermined	2	6	3
Cigarette smoking+			
None	6	4	7
Moderate (<20/day)	3	4	0
Heavy (>20/day)	18	29	9
Alcohol ingestion			
Infrequent or none	18	20	5
Moderate (<3 oz/day)	8	14	10
Heavy (>3 oz/day)	1	3	1
Vocational physical activity			
None	14	20	7
Moderate	8	15	9
Heavy	5	2	0
Avocational physical activity			
None	11	18	7
Moderate	13	14	5
Heavy	3	5	4

Table VII - Continued

*Significantly greater (P>.001) frequency of Type A behavior pattern in the subjects dying of cardiac disease than in those subjects dying of noncardiac causes.

+Significantly greater (P>.005) frequency of moderate and heavy smoking in the subjects dying of cardiac disease than in those subjects dying of noncardiac causes.

Analysis showed that Type A behavior pattern was a significant risk factor for sudden death. In addition, cigarette smoking was a significant risk factor for sudden death. Alcohol consumption appeared to be a protective factor in this study but was not significant; however, a subsequent study has shown that alcohol consumption does have some protective value (13). Physical activity appears unrelated to sudden death and is similar to that found in many healthy individuals of the same age.

Prior medical findings were also evaluated by Friedman as shown in Table VIII (12).

Table VIII. Prior Medical Findings in Instantaneous and Sudden Death Cases (12).

	Instantaneous Cardiac Deaths	Sudden Cardiac Deaths	Instantaneous and Sudden non-cardiac Deaths
Number of cases	27	37	16
Parental history*	14	20	3
Prior relevant diseases*			
Hypertension	8	14	6
Diabetes	3	7	1
Hypercholesterolemia+	6‡	5§	0‖
Obesity	7	20	3
Prior coronary disease #			
Yes	13	14	1
Previous infarct	9	8	0
Angina	7	8	1
Abnormal ECG	13**	11++	0‡‡
Prior medications			
Digitalis glycosides	5	3	0
Antiarrhythmic Drugs	3	1	0
Antidabetic drugs, orally taken	2	3	1
Insulin	0	2	0
Nitroglycerine	5	3	0
Under regular medical surveillance	11	14	4
Last medical visit before death			
< 1 week	5§§	4‖‖	5¶¶
< 3 weeks	7	5	5
> 3 weeks	19	28	6

*Significantly greater frequency of positive parental cardiac disease history (P>.005) in the subjects who died of cardiac disease than in those subjects who died of noncardiac causes.
† Serum cholesterol, >270 mg/100 ml.
± Previous cholesterol data were obtained in 18 of the 27 instantaneous coronary death cases
§ Previous cholesterol data were obtained in 10 of the 37 sudden coronary death cases
‖ Previous cholesterol data were obtained in 10 of the 16 instantaneous and sudden noncardiac death cases
¶ Weight, 25 or more pounds more than ideal weight
# Significantly greater frequency of prior history of coronary disease (P < .001) infarct (P<.001), angina (P<.001), and abnormal ECG (P<.001) in the subjects who died of cardiac disease than in those subjects who died of noncardiac causes.
** Previous ECGs were examined in 18 of the 27 instantaneous coronary death cases
†† Previous ECGs were examined in 20 of the 37 sudden coronary death cases
±± Previous ECGs were examined in 11 of the 16 instantaneous and sudden noncardiac death cases.
§§ Three of these 5 visits were occasioned by noncardiac symptoms
‖‖ Two of these 4 visits were occasioned by noncardiac symptoms
¶¶ None of these visits were occasioned by cardiac symptoms

x numbers inadequate to determine risks

Analysis revealed that parental history and prior coronary disease were significantly correlated with sudden death. The numbers were inadequate to evaluate hypertension, diabetes, and hypercholesterolemia in this study, but these have been shown to be highly significant in prospective studies.

Sudden death was far more common in men than women (14). While the incidence of myocardial infarction is much higher in white than blacks, there is no difference in the incidence of sudden death due to coronary artery disease as is shown in Table IX (14).

Table IX. Incidence of Sudden ASHD Deaths by Age, Race and Sex (14)

Race, sex	Age 45-54			Age 55-64		
	All	No heart disease		All	No heart disease	
		Total	Within 15 min.		Total	Within 15 min.
WM	22.0	14.0	3.0	45	17	4.0
WF	5.0	2.0	0.6	10	5.0	1.0
BM	20.0	14.0	2.0	36	21	2.0
BF	4.0	1.0	0.5	12	5.0	1.0
Ratio						
WM/WF	4.4	7.0	5.0	4.5	3.4	4.0
WM/BM	1.1	1.0	1.5	1.3	0.8	2.0
BM/BF	5.0	14	4.0	3.0	4.2	2.0
BF/WF	1.2	2.0	1.2	0.8	1.0	1.0

Table IX. Continued

*Classified according to the following sets of criteria: 1) all ASHD sudden deaths; 2) those with no history of heart disease; and 3) no history of heart disease, and death witnessed as occurring within 15 minutes.

Based on reports of Baltimore City Vital Statistics, Eighth revision of International Classification of Disease by age and sex, per 100,000.

Abbreviations: WM = white male; WF = white female; BM = black male; BF = black female.

It is of interest to compare this with the incidence of myocardial infarction from the same population in Table X (14).

Table X. Incidence of Transmural Myocardial Infarction (Survivors of Hospital Only) By Age, Race, and Sex, per 10,000 per Year, in Patients With No Prior History of Heart Disease (14).

Race, sex	Age	
	45-54	55-64
WM	19	29
WF	4	11
BM	6	8
BF	2	10
Ratio to sudden ASHD deaths		
WM	1.4	1.7
WF	2.0	2.2
BM	0.4	0.4
BF	2.0	2.0

Based on reports of Baltimore City Vital Statistics, Eighth revision of International Classification of Disease by age and sex, per 100,000.

Abbreviations: WM = white male; WF = white female; BM = black male; BF = black female.

Hence, men with ASHD have a greater risk of sudden death than women with ASHD. Blacks with ASHD are more likely to have sudden death than whites as manifestations of their ASHD.

Thus, the classic risk factors for ASHD are also risk factors for sudden death. However, sex and race have a different distribution in sudden death from ASHD in general. Ventricular premature beats and other ECG abnormalities are risk factors for sudden death but not for ASHD in general.

Clinical presentations

Many patients have some prodromal syndromes. In Table XI are shown the prodromal symptoms seen in patients who have subsequent myocardial infarctions.

Table XI. Prodromal Symptoms of Myocardial Infarction (33).

Author, year	No. of patients	Frequency of symptoms or sign (%) All symptoms	Chest Pain	Fatigue	Dyspnea	Consulted M.D. within 1 mo.
Feil, 1937 (15)	--	--	50	--	--	--
Sampson & Eliaser, 1937 (16)	27	--	48	--	--	--
Master et al, 1941 (17)	260	44	25	8	2	--
Waitzkin, 1944 (18)	61	--	28	--	--	--
Mounsey, 1951 (19)	139	--	29	--	--	--
Khosla & Caroli, 1964 (20)	98	--	56	--	--	--
Solomon et al, 1969 (21)	100	65	59	--	--	--
Moss et al, 1969 (22)	64	55	39	--	--	--
Kinlen, 1969 (23)	194	--	49	--	--	--
Stowers & Short, 1970 (24)	180	68	55	7	4	35
Moss & Goldstein, 1970 (25)	160	51	--	--	--	--
Hochberg, 1971 (26)	74	84	69	15	18	--
Fulton et al, 1972 (27)	121	49	44	--	--	--
Simon et al, 1972 (28)	160	70	48	27	25	--
Romo, 1972 (29)	736	67	35	--	--	36
Nixon & Bethell, 1974 (30)	40	--	52	77	25	--
Gillum et al, 1975 (31)	73	95	70	68	26	40
Total	2487	63	42	21	12	36

In comparison is shown the prodromal symptoms of sudden death in Table XII.

Table XII. Prodromal Symptoms of Sudden Death (33)

Author, year	No. of patients	Frequency of symptom or sign (%) All symptoms	Chest Pain	Fatigue	Dyspnea	Consulted M.D.
Kinlen, 1969 (23)	142	--	33	41	--	25 (1 wk)
Kuller et al, 1972 (32)	208	--	37	56	42	28 (2 wks)
Romo, 1972 (29)	239	53	15	--	--	37 (2 wks)
Simon et al, 1973 (28)	138	65	22	26	26	39 (2 wks)
Friedman et al, 1973 (12)	64	17	11	13	5	19 (3 wks)
Liberthson et al, 1974 (33)	300	29	--	--	--	29 (4 wks)
Gillum et al, 1975 (31)	19	79	32	68	21	37 (2 wks)
Total	1110	43	25	31	30	31

Hence the incidence of chest pain prodromal appears to be less with sudden death while nonspecific complaints tend to be more common.

Friedman (12) has categorized prodromal symptoms and other activities in patients with instantaneous cardiac deaths (< 1 minute) sudden cardiac death (> 1 minute, < 24 hours) and instantaneous and sudden noncardiac deaths as shown in Table XIII.

Table XIII. Various Clinical Aspects of Terminal Episode in Instantaneous and Sudden Death Cases (12).

	Instantaneous Cardiac Death Cases	Sudden Cardiac Death Cases	Instantaneous and Sudden Noncardiac Death Cases
No. of cases	27	37	16
Subjects experiencing prodromal symptoms	2	9	8
Increased dyspnea	0	3	1
Beginning or increased angina	1	6	0
Excessive fatigue	2	6	2
Palpitation	0	0	0
Other symptoms	0	3	5
Last food intake			
Minutes before onset	262	250	246
Heavy	9	12	5
Moderate or light	18	25	11
Activity immediately prior to terminal episode			
Severe physical activity	10	1	0
Moderate physical activity	4	2	0
Sitting or reclining	9	23	7
Sleeping	2	6	0
Standing	1	5	1
Eating	0	0	1
Driving	0	0	7
Sexual intercourse	0	0	0
Defecation	1	0	0
Average time of death	1:32 PM	2:35 PM	3:29 PM
Subjects experiencing major acute symptoms	0	37	8
Pain (chest, neck, shoulder, arm, abdomen)	0	34	2
Dyspnea	0	17	3
Faintness-weakness	0	16	4
Nausea-vomiting	0	12	1
Sudation	0	6	1
Paresthesia	0	3	0
Palpitation	0	2	0

Table XIII Continued

	Instantaneous Cardiac Death Cases	Sudden Cardiac Death Cases	Instantaneous and Sudden Noncardiac Death Cases
Acute signs			
Collapse-unconscious	27	37	16
Pallor or cyanosis	10	11	6
Ventricular fibrillation	7	1	0
Terminal episode - minutes	< 1	138*	264+

*Six subjects died within 15 minutes after onset of symptoms, and only 5 subjects survived five hours or more after onset.
+Eight subjects died in less than 1 minute after onset of terminal episode. The average duration of life, in the remaining 8 subjects, after onset of the terminal episode, was 264 minutes.

It is of interest to note that severe physical activity was mostly seen in instantaneous death suggesting that this may be etiologically important in one third of the instantaneous deaths but not in sudden cardiac deaths which were not instantaneous.

Pathologic correlates

The role of coronary thrombosis has been controversial both in sudden death and myocardial infarction. Herrick originated the theory that coronary artery thrombosis occurred first followed by ischemic infarction (34). More recent observations have made Herrick's hypothesis controversial. Spain and Bradess have observed that only 16% of coronary artery disease patients dying within one hour of onset of symptoms had thrombotic occlusion of a coronary artery, whereas 54% of those who survived 24 hours or more had a thrombus in a coronary artery (35, 36). Roberts and Buja confirmed their observations, reporting a 54% incidence of thrombosis during transmural myocardial infarction and an 8% incidence among patients who died suddenly (37). Table XIV summarizes the incidences of thrombosis during myocardial infarction and sudden death from several series.

Table XIV. Frequency of Thrombotic Occlusion in Myocardial Infarction (MI) and in Sudden Cardiac Death (SD)

Category	Authors	Frequency of thrombotic Occlusion (%)
Recent transmural MI	Chandler et al.(38)	86 - 96
Predominantly subendocardial	Miller et al. (39)	11.0
SD	Crawford et al. (40)	54.6
SD	Kuller (41)	31.0
SD	Spain et al. (42)	19.0
SD	Luke and Helpern (5)	25.6
SD	W.H. Organization (43)	25.9
SD	Crawford (44)	41.0
SD	Mitchell and Schwartz (45)	31.6
SD	Roberts and Buja (37)	8.5
SD (within 30 sec)	Friedman et al. (12)	4.0
SD (within 10 min)	Haerem (46)	29.8
SD (within 15 min)	Jorgensen et al. (47)	33.0
SD (within 1 hr)	Spain and Bradess (48)	17.5
SD (within 1 hr)	Scott and Briggs (49)	33.0
SD (within 2 hr)	Adelson and Hoffman (50)	33.0
SD (within 24 hr)	Friedman et al. (12)	82.0

As can clearly be seen the incidence of thrombosis increases with the duration of symptoms prior to death. This has led Roberts and Buja (37) and Baroldi (51) to argue that myocardial ischemia precedes rather than follows coronary thrombosis, and may in fact play a role in the generation of thrombosis; they have suggested that infarction may occur first followed by swelling which impedes perfusion leading to stasis in a diseased vessel which secondarily thromboses. It is clear that coronary thrombosis appears to be a rarity among patients with instantaneous death, although coronary artery disease of an advanced and extreme degree often involving three vessels with critical obstruction or complete occlusion, is usually present (12). The role of hemorrhage into a plaque appears to be an infrequent cause of sudden death.

The frequency of myocardial infarction in association with sudden death has varied from 13% (37) to 47% (51). Among individuals who were felt to be healthy before the event, coronary artery disease was the usual cause of sudden death (5), with the coronary artery disease

triggering ventricular fibrillation (52,53). In the Framingham study, two-thirds of the deaths within one hour occurred outside the hospital predominantly from coronary artery disease with 50% of them being free of apparent disease prior to their death (54).

Friedman et al (55) found some degree of atherosclerosis in virtually all of of his patients (Table XV).

Table XV. Autopsy Evidence Concerning Coronary Arteries (55).

Description of coronary arteries	Cases in each category No.	% of 141 with autopsy
No more than mild atherosclerosis	1	0.7
Moderate atherosclerosis only	5	3.5
Severe atherosclerosis only	49	31.8
Moderate or severe atherosclerosis with recent occlusion	44	31.2
Moderate or severe atherosclerosis with old occlusion	25	17.7
Moderate or severe atherosclerosis with both recent and old occlusion	17	12.1

Recent occlusions occurred in 43.3% of his patients, with no occlusion at all occurring in 36% of the patients. Hence as in other series, occlusion does not correlate well with sudden death.

The incidence of necrosis or infarction was also studied by Friedman (Table XVI).

Table XVI. Autopsy Evidence Concerning Myocardium (55)

Description of myocardium	Cases in each category No.	% of 141 with autopsy
No infarcts or scarring	36	25.5
Diffuse fibrosis only	12	8.5
Recent infarction(s)	21	14.9
Old infarction(s)	59	41.8
Both recent and old infarctions	10	7.1
Autolyzed	3	2.1

Recent infarctions were only seen in 22% of Friedman's patients. No infarction at all was found in 34% of the patients. Hence pathologic evidence of occlusion or infarction only occurs in 1/3 of the patients with sudden deaths raising questions as to methodology of identifying early infarction or to its etiology of sudden death.

Liberthson et al (33, 56, 57) has shown that single vessel disease is more common with sudden death and inferior infarction is more common than anterior infarction (Table XVII).

Table XVII. Pathologic Characterization of Sudden Cardiac Deaths[a] (56).

	Percent of total	Percent within category
Acute coronary occlusion	58	
Single vessel		84
Multiple vessel		16
Ruptured plaque		56
Thrombosis		32
Intramural hemorrhage		10
Embolus		2
Acute myocardial infarction	27	
Anterior wall		22
Anterior and inferior wall		12
Inferior wall		66
Very fresh (1 day)		17
Fresh (1-3 days)		39
Recent (3-7 days)		17
Organizing (1 week)		27

[a] 220 autopsies

It should be noted however that infarction was found in only 27% of Liberthson's patients.

Table XVIII (65)

Frequency of Occurrence of Clinical and Pathologic Findings of Several Reported Series of Sudden Cardiac Death (SCD)

	Kuller et al.[58]	Titus[59]	Friedman et al.[12]	Friedman et al.[12]	Liberthson et al.[33]	Liberthson et al.[33]	Roberts and Buja[37]	Schwartz and Gerrity[60]	Perper et al.[61]	Lie and Titus[62]	Baba and Bashe[63,64]	Reichenbach and Moss[65]
Cases (no.)	486	286	27	37	70	150	24	19	169	120	121	87
Male sex	73%	74%	...	...	87%	87%	83%	...	...	...	...	86%
Age (yr)	25–64	58.7	≤66 m̄ = 54	≤66 m̄ = 54	55	52	54	...	25–64	59	<65	63
Definition of sudden death	Within 24 hr	Within 1 hr	Within 30 sec	Within 24 hr	SCD—hospital death	SCD—unresuscitated	<6 hrs	...	Within 24 hr	Within 6 hr	Within 24 hr	Within 12 hr
Prior history of:												
Heart disease	47%	...	...	...	...	...	...	...	...	...	36%	97%
Myocardial infarction	...	...	33%	22%	30%	24%	...	...	...	...	18%	48%
Angina	...	...	26%	22%	56%	43%	...	...	...	...	14%	66%
Hypertension	38%	...	...	...	...	...	46%	...	...	...	...	36%
Digitalis use	...	...	19%	8%	...	...	...	...	...	...	...	33%
Nitroglycerin use	...	...	19%	8%	...	...	...	...	...	...	...	30%
Ventricular fibrillation	...	...	26%	3%	74%	...	...	...	...	...	...	39%
Activity at time of collapse												
Heavy physical activity	...	...	37%	3%	20%	22%	...	...	...	...	...	6%
Sitting	...	...	33%	62%	21%	23%	...	...	...	...	...	41%
Myocardial infarction												
Old	45%	22%	56%	50%	49%	42%	62%	37%	43%	41%	39%	55%
Anterior and anteroseptal	...	...	12%	15%	18%	21%	...	...	...	...	20%	23%
Posterior and posteroseptal	...	...	36%	29%	58%	47%	...	...	...	...	23%	44%
Greater than 75 percent coronary narrowing involving:												
0 vessel	...	...	8%	6%	10%	4%	...	...	9%	...	...	8%
1 vessel	...	...	12%	18%	13%	14%	12%	...	15%	...	...	16%
2 vessels	...	...	16%	21%	22%	26%	42%	...	15%	...	...	36%
3 vessels	...	...	40%	35%	65%	60%	46%	...	38%	...	...	36%
4 vessels	...	...	24%	21%	...	...	...	...	23%	...	...	...
100 percent coronary narrowing												
0 vessel	...	...	24%	53%	...		...	...	...	...	...	...
1 vessel	...	...	32%	41%	1%		...	...	...	...	...	40%
2 vessels	...	...	24%	16%	7%		...	...	...	...	...	16%
3 vessels	...	...	20%	0%	27%		...	...	...	...	...	1%
Distribution of lesions by artery:												
Percent narrowing	...	>50%	100%	100%	...	...	...	...	>90%	...	...	100%
Left anterior descending		96%	52%	3%					43%			23%
Right	...	79%	48%	32%	...	...	...	...	34%	...	...	34%
Circumflex	...	66%	32%	21%	...	...	...	...	30%	...	...	21%
Left main	...	34%	4%	3%	...	...	...	...	13%	...	...	0%
Acute thrombi	15%	18%	4%	59%	19%			32%		17%	38%	10%
Acute myocardial infarction	...	...	0%	21%	27%	27%	...	32%	11%	33%	12%	5%
Anterior	...	...	...	...	11%	28%	...	...	...	...	12%	...
Inferior	...	...	...	...	78%	60%	...	...	...	...	5%	...

m = mean.

Table XVIII from Reichenbach and Moss (65) on the last page summarizes the major pathologic series in the literature. It is apparent from these studies that old myocardial infarctions were present in about one-half of the patients with inferior infarctions being twice as prevalent as anterior infarctions. Coronary artery disease was usually present with one-third of the patients having 2 vessel disease and one-third having three vessel disease. Complete occlusions of 3 vessels were more common in patients with instantaneous death than in those dying within 24 hours. Distribution between the three coronary arteries were equal but left anterior descending occlusions were more frequent in instantaneous death (>1 minute) than in sudden death (>24 hours). Acute infarctions were uncommon but inferior infarctions seemed to predominate again.

Reichenbach and Moss have analyzed sudden deaths by the initial rhythm found by the paramedics in the Seattle system (65). These will be summarized in the following Tables XIX and XX.

Table XIX(65).

Age and Selected Clinical Data on Patients Grouped by Electrocardiographic Rhythm at Initiation of Resuscitation

	Ventricular Fibrillation	Asystole	Other Rhythm	No ECG Available	Total
Cases (no.)	34	26	12	15	87
Age (mean ± SD) (yr)	63 ± 10	69 ± 11	67 ± 16	54 ± 11	63 ± 12
History of prior cardiac symptoms in all cases with available history	33/34 (97%)	26/26 (100%)	12/12 (100%)	13/15 (87%)	84/87 (97%)
Occurrence of symptoms within 1 week of collapse*	11/34 (32%)	8/26 (31%)	9/12 (75%)	3/15 (20%)	31/87 (36%)
History of taking any cardiac medications	24/28 (86%)	20/23 (87%)	10/12 (83%)	7/10 (70%)	61/73 (84%)
History of taking digitalis or nitroglycerin	16/28 (57%)	14/23 (61%)	9/12 (75%)	6/10 (60%)	45/73 (62%)
History of myocardial infarction or angina	31/34 (91%)	20/26 (77%)	10/12 (83%)	12/15 (80%)	73/87 (84%)
Collapse witnessed*	25/34 (74%)	5/26 (19%)	11/12 (92%)	8/15 (53%)	49/87 (56%)

*Significant $P < 0.05$. ECG = electrocardiogram.

As is shown in Table XIX, there were no differences between the type of rhythm found by the paramedics and historical data save for whether the collapse was witnessed and symptoms within 1 week of collapse. Far fewer patients with asystole were witnessed to collapse. This is probably due to the fact that most patients arrest with ventricular fibrillation and deteriorate into asystole with time if no resuscitation is initiated; hence most patients with asystole probably have been arrested for several minutes and were not witnessed. Other rhythm also had more symptoms as these patients probably had prior damage, went into pump failure and then into electromechanical dissociation.

In Table XX are shown the pathologic correlates by rhythm. The only significant finding was more recent information in the other category which supports the hypothesis that these patients had symptoms referable to infarction or pump failure, followed by electromechanical dissociation.

Table XX. (65)

Coronary and Myocardial Pathologic Changes Grouped by Electrocardiographic Rhythm at the Initiation of Resuscitation

	Ventricular Fibrillation	Asystole	Other Rhythm	No ECG Available	Total
Cases (no.)	34	26	12	15	87
Myocardial infarction					
None	9/34 (26%)	11/26 (42%)	4/12 (33%)	5/15 (33%)	29/87 (33%)
Recent*	0	0	3/12 (25%)	1/15 (7%)	4/87 (5%)
Healing	10/34 (29%)	3/26 (12%)	3/12 (25%)	2/15 (13%)	18/87 (21%)
Old	21/34 (62%)	14/26 (54%)	5/12 (42%)	10/15 (67%)	50/87 (57%)
Acute thrombosis	3/34 (9%)	2/26 (8%)	2/12 (17%)	2/15 (13%)	9/87 (10%)
Coronary disease					
Less than 75 percent reduction in area in any major vessel	2/34 (6%)	3/26 (12%)	1/12 (8%)	1/15 (5%)	7/87 (8%)
Complete occlusion in one or more vessels	21/34 (62%)	14/26 (54%)	6/12 (50%)	10/15 (63%)	51/87 (59%)
Single vessel with 90 percent or greater obstruction and less than 75 percent obstruction in the others	3/34 (9%)	3/26 (12%)	0/12 (0%)	1/15 (11%)	7/87 (8%)
Two vessels with 90 percent or greater obstruction and less than 75 percent obstruction in the other	7/34 (21%)	4/26 (15%)	2/12 (17%)	3/15 (21%)	16/87 (18%)
Three vessels with 90 percent or greater obstruction	4/34 (12%)	2/26 (8%)	1/12 (8%)	4/15 (27%)	11/87 (13%)

*Significant $P < 0.05$.
ECG = electrocardiogram.

Reichenbach et al (65) also analyzed the same factors by age and found no correlation between age and any of the factors studied as shown in Tables XXI and XXII.

Table XXI. (65).

Electrocardiographic Rhythm at Initiation of Resuscitation and Selected Clinical Information Compared by Age

	≤46 Years	46–55 Years	56–65 Years	66–75 Years	≥76 Years	Total
Cases (no.)	4	22	22	21	18	87
Ventricular fibrillation	1	9	11	8	5	34
Asystole	0	4	4	10	8	26
Other rhythm	1	1	4	2	4	12
No ECG	2	8	3	1	1	15
History of prior cardiac symptoms	4/4	20/22 (91%)	22/22 (100%)	20/20 (100%)	18/18 (100%)	84/87 (97%)
History of myocardial infarction or angina	4/4	19/22 (86%)	21/22 (95%)	18/20 (86%)	11/18 (61%)	73/87 (84%)
History of taking any cardiac medication	1/2	13/17 (76%)	19/21 (90%)	16/19 (84%)	12/14 (86%)	61/73 (84%)
Collapse witnessed	4/4	14/22 (64%)	13/22 (59%)	9/21 (45%)	9/18 (50%)	49/87 (56%)

ECG = electrocardiogram.

Table XXII (65).

Coronary and Myocardial Changes Grouped by Age in Patients Who Died Suddenly

	<45 Years	46–55 Years	56–65 Years	66–75 Years	≥76 Years	Total
Cases (no.)	4	22	22	21	18	87
Myocardial infarction						
None	1/4 (25%)	8/22 (36%)	6/22 (27%)	6/21 (33%)	8/18 (44%)	29/87 (33%)
Recent	0	1/22 (5%)	0	2/21 (10%)	1/18 (6%)	4/87 (5%)
Healing	2/4 (50%)	8/22 (36%)	4/22 (18%)	3/21 (14%)	1/18 (6%)	18/87 (21%)
Old	2/4 (50%)	12/22 (55%)	14/22 (64%)	12/21 (57%)	10/18 (55%)	50/87 (57%)
Acute thrombosis	0	4/22 (18%)	1/22 (5%)	2/21 (10%)	2/18 (11%)	9/87 (10%)
Coronary disease						
Less than 75 percent reduction in area in any major vessel	0	0	2/22 (9%)	2/21 (10%)	3/18 (22%)	7/87 (8%)
Complete occlusion in one or more vessels	0	15/22 (68%)	13/22 (59%)	12/21 (57%)	11/18 (61%)	51/87 (59%)
Single vessel with 90 percent or greater obstruction and less than 75 percent obstruction in the others	1/4 (25%)	1/22 (5%)	0	4/21 (24%)	1/18 (6%)	7/87 (8%)
Two vessels with 90 percent or greater obstruction and less than 75 percent obstruction in the other	0	6/22 (27%)	5/22 (23%)	0	5/18 (28%)	16/87 (18%)
Three vessels with 90 percent or greater obstruction	0	4/22 (18%)	3/22 (14%)	2/21 (10%)	2/18 (11%)	11/87 (13%)

Survivors of Sudden Death - Other systems

The development of emergency medical systems in the United States over the last decade has allowed us to gain new insight into sudden death.

When the incidence of successful resuscitation from cardiac arrest in ambulance units is examined in those patients who had onset of resuscitation within 5 minutes of arrest, the results are surprisingly good (66). (Table XXIII).

Table XXIII - Prehospital Correction of Cardiac Arrest in Acute Myocardial Infarction

Source	Onset Resuscitation Under 5 Minutes After Arrest (Number)	Left Hospital to Resume Normal Life	
		Number	Percent
Belfast (67)	36	24	66.6
Ballymena (68)	5	3	60.0
Dublin (69)	20	11	55.0
Portland (70)	14	7	50.0
Brighton (71)	8	5	62.5
Seattle (72)	24	21	87.5
Charlottesville (73)	15	10	66.5
Columbus (74)	15	8	53.3
Waynesboro (75)	3	2	66.6
Lincoln (66)	8	7	87.5
Total	148	98	66.2

It is of interest to note that the success was the same whether a physician and nurse were at the scene or the arrest was handled by paramedical personnel. Therefore, paramedics appear to perform very adequately in this role.

Pantridge has reported that the success of resuscitation is related to the time between arrest and onset of therapy and the efficiency of therapy (76-78). (Table XXIV).

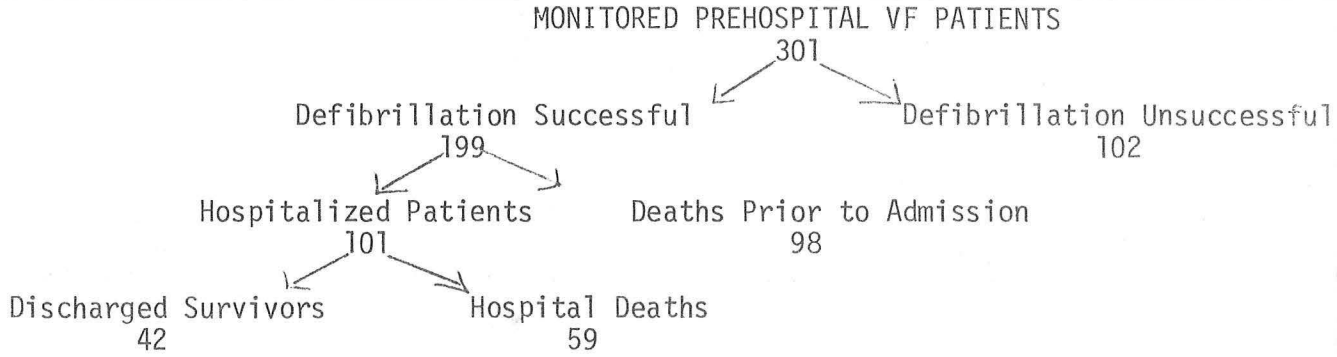
Table XXIV.

		Vent Fib		Asystole	
	Total	No	Survivors	No	Survivors
No resuscitation within 4 min	106	21	1	85	0
Resuscitation within 4 min (inefficient)	37	27	14(52%)	10	0
Resuscitation within 4 min (efficient)	50	46	40(87%)	4	0

Of the 55 initial survivors, 38 left the hospital. From these data several things are apparent. First, resuscitation is more successful the earlier it is started. Second, patients with asystole have a far worse prognosis than ventricular fibrillation. And, third, the initial rhythm is usually ventricular fibrillation while asystole tends to occur later; hence, most patients probably initially have ventricular fibrillation and if resuscitation is not started they go into asystole in 3-4 minutes.

Nagel and associates from Miami have studied survivors of ventricular fibrillation resuscitated outside the hospital as shown in Figure III (78-82).

Figure III - Results of Resuscitations in Miami System (79-82).



Hence, it appears that one of six patients with prehospital ventricular fibrillation can survive with an adequate mobile coronary care unit. Details of these patients have revealed that the prodromal are similar to those from post mortem studies as is shown in Table XXV (84).

Table XXV - Events Preceding Sudden Cardiac Death[a](84)

Event	Percent
New chest pain or dyspnea within 1 day	25
Acute symptoms for less than 30 minutes	25
Instantaneous collapse	50
Old myocardial infarction	41
Angina pectoris	54
New or changing symptoms within four weeks	27

[a] 426 patients

In Nagel's series, the predominant rhythm was ventricular fibrillation as shown in Table XXVI (81).

Table XXVI - Prehospital Sudden Cardiac Deaths--ECG Patterns Present on Arrival of Rescue Squad[a] (81)

Pattern	Percent
Ventricular fibrillation	72
Idioventricular rhythm	8
Asystole	8
Junctional rhythm	7
Sinus bradycardia	2
Atrioventricular block	2
Ventricular tachycardia	1

[a] 426 patients

The survivors had a similar history to the non-survivors as shown in Table XXVII (81).

Table XXVII - Characterization of Defibrillated Survivors[a] (81)

	Percent
History of old myocardial infarction	52
History of angina pectoris or chest pain	50
History of hypertension	35
Smoking more than 10 cigarettes a day	42
New or changing symptoms within 4 weeks	28
Warning symptoms on day of acute event	17
Acute terminal symptoms only	19
Sudden collapse without prior symptoms	65
Location of acute event	
Home	48
Work	6
Public Place	46
Activity immediately before acute event	
Rest or sleep	15
Mild or moderate	69
Strenuous or stressful	16
Estimated mean interval from collapse to electrocardiography (minutes)	15.3

[a] 101 surviving patients

From Nagel's series only 35% of the patients had evidence of myocardial infarction while another 32% had evidence of ischemia as shown in Table XVIII (81).

Table XVIII - ECG Characterization of Defibrillated Survivors[a] (81)

	Patients (Percent)	
Acute myocardial infarction	35	
Anterior wall		46
Anterior and inferior wall		13
Inferior wall		41
Ischemia without infarction	32	
Anterior wall		66
Anterior and inferior wall		28
Inferior wall		6
No acute EKG change	17	
Complete left bundle branch block[b]	17	

Table XVIII Continued.

a
101 surviving patients

b
possibly masking an acute myocardial change

Nagel et al have also shown that the survival rate is dependent upon the rhythm after defibrillation. As shown in Figure 4, the higher the rate after defibrillation, the greater the chance of survival (80,82).

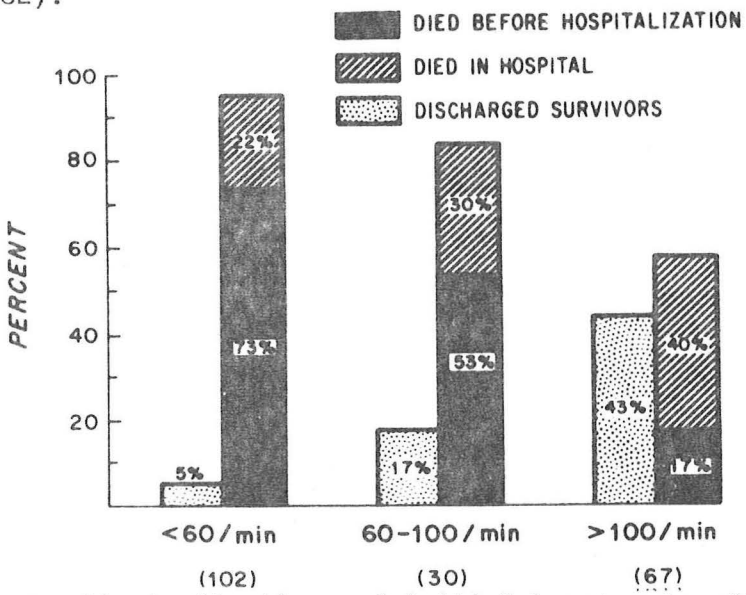


Figure 4. Prognostic implications of initial heart rate after defibrillation. Prehospital and hospital deaths and long-range survival after prehospital defibrillation are compared to the initial post-defibrillation heart rate whether less than 60, between 60 and 100, and more than 100 beats per minute (80,82).

Cobb and coinvestigators from Seattle have extensively studied survivors from their system (83,84). In Figure 5, the success of the system in handling prehospital ventricular fibrillation are shown (84). In the first 2 years, they were able to resuscitate 34% with 11% going home. In the subsequent 2 years, they were able to resuscitate 43% with 23% going home. This improvement was not only due to refinements in their system but also to a wide-spread program of citizen CPR to a degree that in one-half of the cases someone is doing CPR when the paramedics arrive (84).

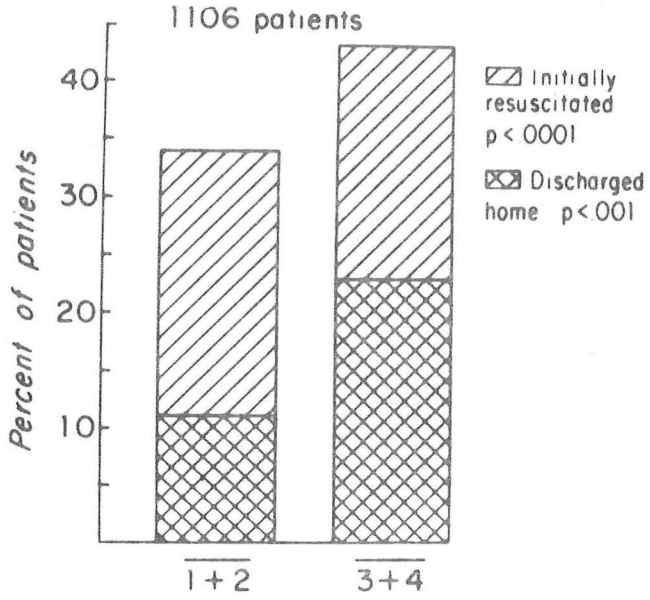


Figure 5. Outcome in 1106 patients with ventricular fibrillation present on arrival of the fire department units. The experience between the first 2 years (511 patients) and the subsequent 2 years (595 patients) is compared (84).

The importance of citizen CPR is pointed out in Table XXIX, which plots the probability of admission to hospital to the time of arrival of definitive care (85).

Table XXIX (85).

PROBABILITY OF ADMISSION
Time to Initiation of CPR (TCPR) (min)

Time to Definitive Care (TDC) (min)	2	3	4	5	6	7	8
2	.64						
4	.61	.58	.55				
6	.58	.55	.51	.48	.45		
8	.54	.51	.48	.45	.41	.38	.35
10	.51	.48	.45	.41	.38	.35	.32
14	.44	.41	.38	.35	.32	.29	.27
18	.38	.35	.32	.29	.26	.24	.22
22	.32	.29	.26	.24	.21	.19	.17
26	.26	.24	.21	.19	.17	.15	.14
30	.21	.19	.17	.15	.14	.12	.11

$$p = 1 - \frac{1}{1 + \exp[(.982 - 131\,(TCPR) - .068(TDC)]}$$

(Equation based on logistic analysis of 254 cases)

As can clearly be seen the earlier both paramedics and citizens arrive, the better the chances of survival. As the average time for paramedics to arrive is between 6-8 minutes (5 minutes response time and 1-3 minutes for someone to decide to call), citizen CPR is essential to have good survival; in addition, citizen CPR is essential to reduce brain damage which greatly improves both morbidity and mortality (84).

Cobb et al (84) have also evaluated the survivors. Using ECG criteria for infarction Cobb has shown that only 16% of the survivors have acute transmural myocardial infarction as shown in Figure 6 (84).

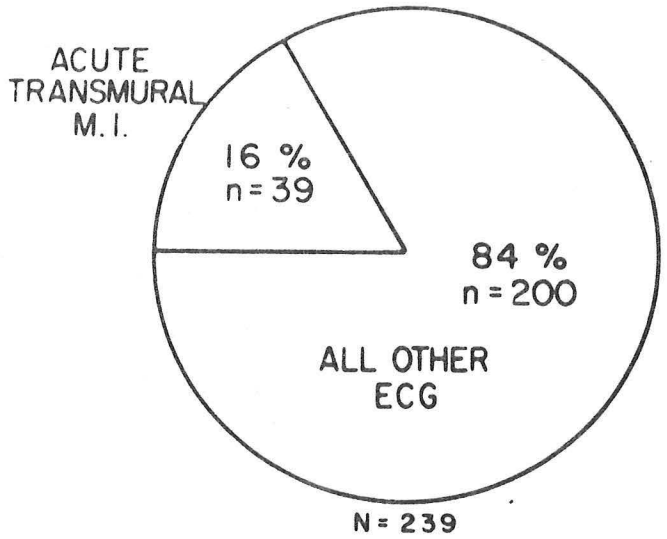


Figure 6. Serial ECG changes in 239 episodes of out-of-hospital ventricular fibrillation. In 39 cases (16%), ECG patterns of acute transmural myocardial infarction (MI) were observed (84).

When Cobb (84) looked at myocardial necrosis as determined by LDH isoenzyme patterns only 45% had evidence of any myocardial necrosis which is quite surprising in that defibrillation by itself causes some myocardial necrosis as is shown in Figure 7 (84).

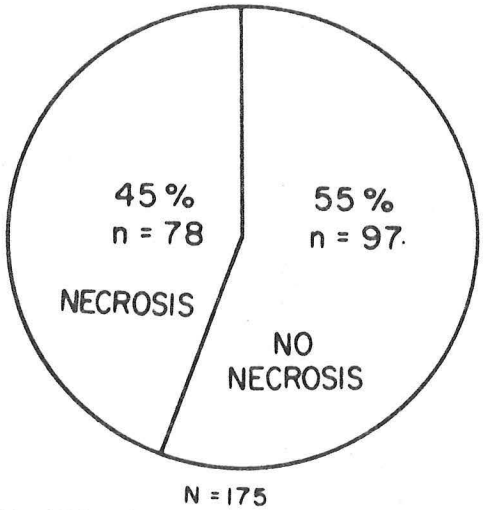


Figure 7. Distribution of ventricular fibrillation episodes according to the presence or absence of myocardial necrosis (84).

When long term followup was obtained the presence or absence of infarction was very important in determining survival. Figure 8 reveals that those patients with transmural myocardial infarction had a much lower recurrence rate than those without infarction (84).

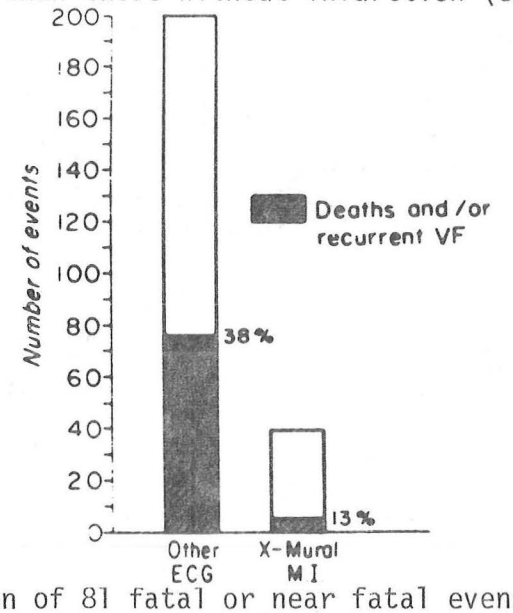


Figure 8. Distribution of 81 fatal or near fatal events during 51 months of followup. Events are classified according to the presence or absence of acute transmural infarction associated with the initial episode of out-of-hospital ventricular fibrillation. Not shown are two events for which serial ECG's were unavailable (84).

When mortality is compared by using a life table it is obvious that the patients with transmural infarction did much better with time than those witout infarction (Figure 9). (84).

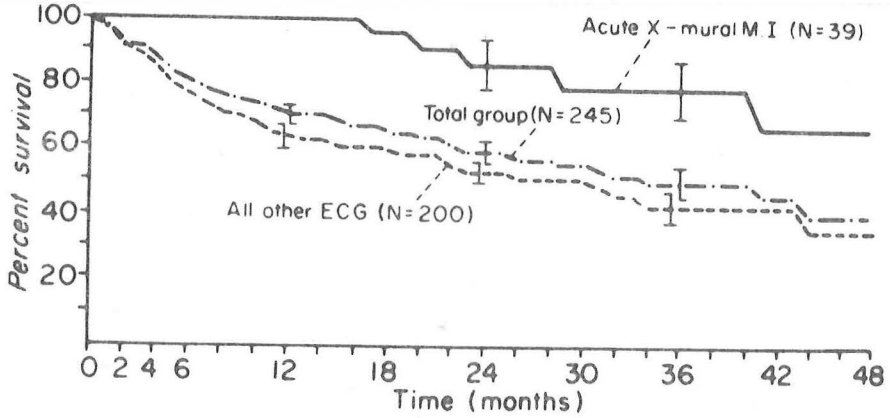


Figure 9. Percent survival following resuscitation through June 1, 1974. The smaller subgroups with acute transmural myocardial infarction showed a significantly greater survival (84).

The same differences were pointed out using myocardial necrosis instead of transmural infarction but the difference in survival was a little less marked (Figure 10)(84).

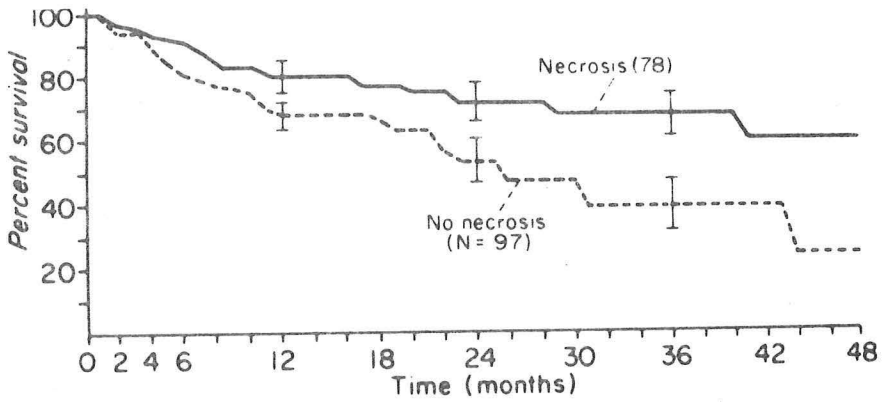


Figure 10. Percent survival in patients with and without necrosis associated with an episode of ventricular fibrillation.

Cobb et al (84) also performed cardiac catheterization in 29 survivors of ventricular fibrillation. In one half of the patients, ventricular function was good as measured by various techniques as is shown in Figure 11 (84).

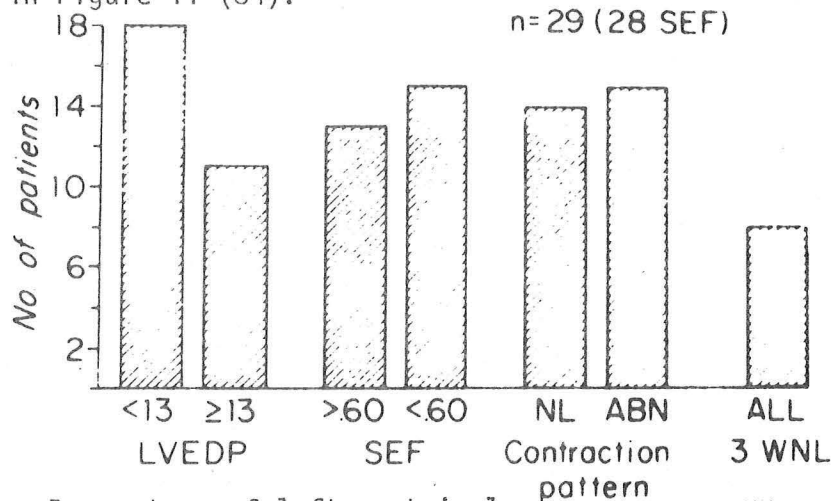


Figure 11. Parameters of left ventricular function in 29 survivors of primary ventricular fibrillation. Left ventricular end-diastolic pressure (LVEDP), systolic ejection function (SEF), and contraction pattern on ventriculography. In one patient, SEF could not be measured (84).

Coronary angiography in these 29 patients revealed 6 patients with no disease, 2 with minimal disease and a distribution of coronary artery disease in the survivors similar to autopsy studies (Figure 12) (84).

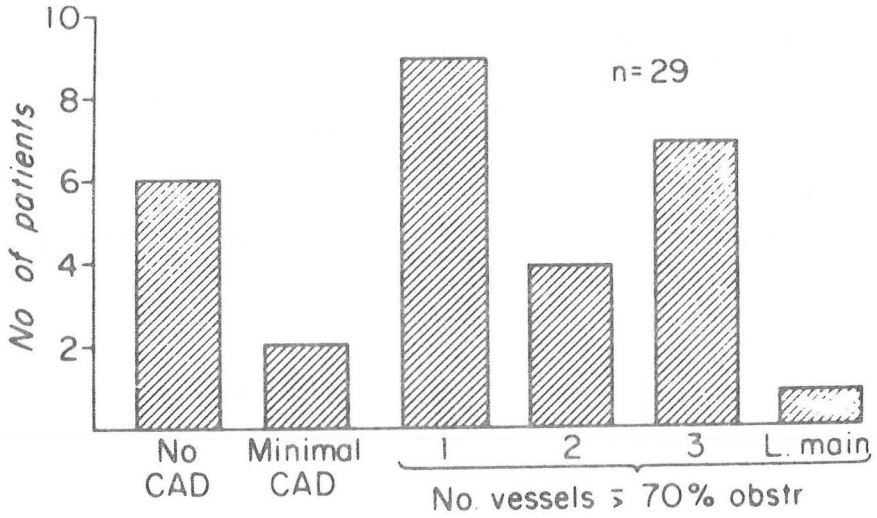


Figure 12. Coronary angiography in 29 survivors of primary ventricular fibrillation. Major coronary arteries with 70% or more obstruction of lumen diameter are identified; not shown are additional lesions of lesser severity. Of the nine patients shown with major single vessel narrowing, only two had isolated single vessel lesions (84).

The most important factor in evaluating these systems is the influence of the system on whole community survival. Crampton et al (86, 87) have reported studies involving communitywide mortality.

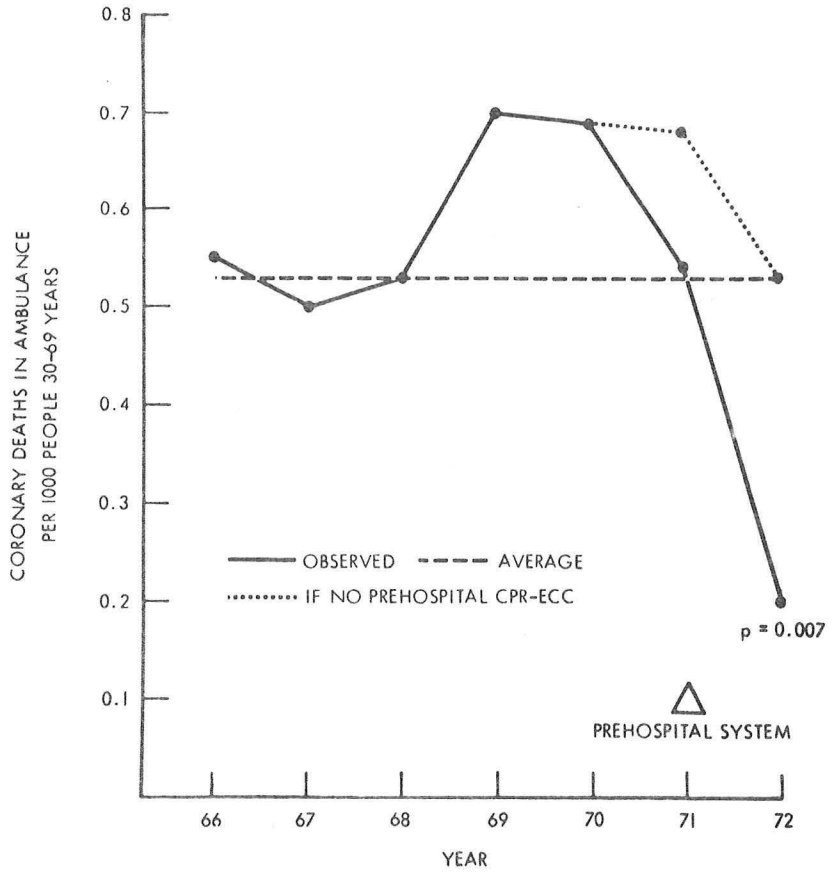


Figure 13. In 1971 and 1972 an advanced prehospital system was utilized. The dotted line represents mortality if no resuscitation was available. The solid line represents the observed mortality. There was a significant reduction of mortality in the ambulance while the patient was being transported.

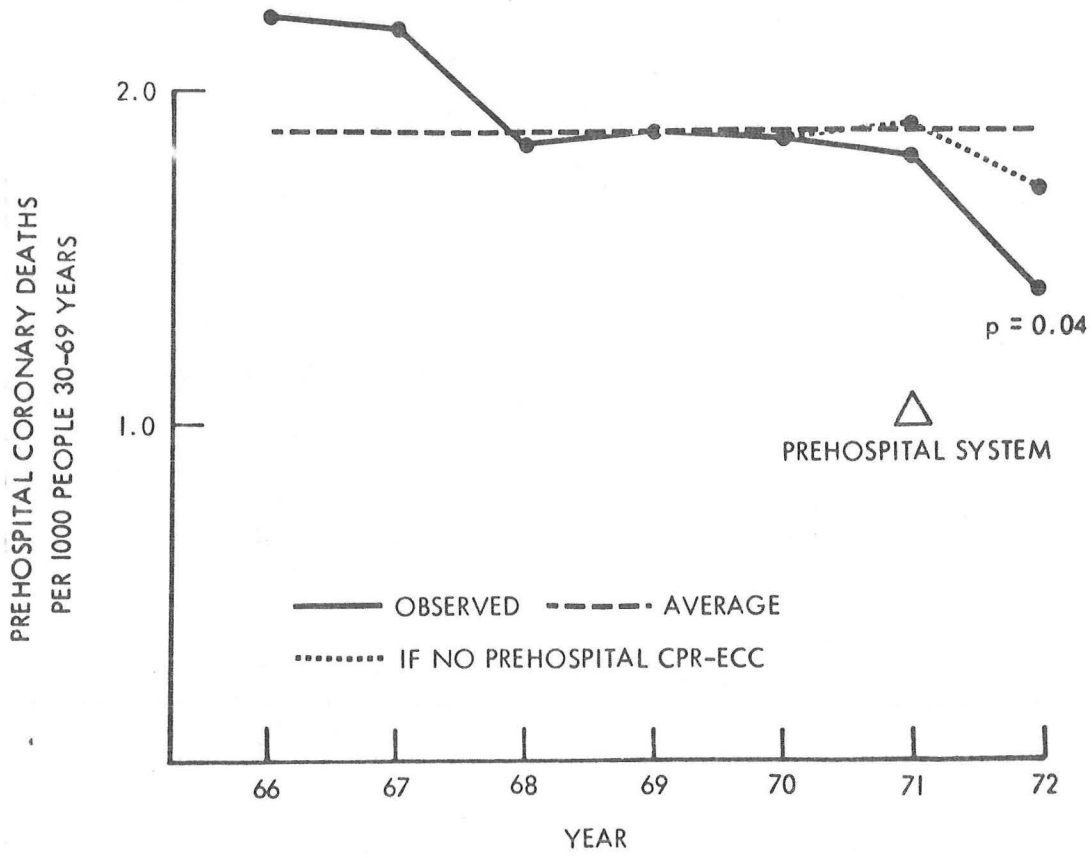


Figure 14. There was also a significant reduction in community mortality in the 30-69 year range. Crampton (86, 87) has shown that the system has saved 15.2 lives/100,000 people aged 30 to 69 years per year. Of total population the salvage rate was 6.4 lives/100,000 population. Webb (88) has found a salvage rate of 8.6 lives/100,000 population annually. When extrapolating these data to the City of Dallas, the system should be able to save 77 to 103 people per year who have ventricular fibrillation.

Dallas Emergency Medical Services

The development of Emergency Medical Services in Dallas in 1974 has altered mortality in our region. In Table XXX are shown the number of patients with pre-hospital cardiac arrest in 1976 and 1977 by initial rhythm.

Table XXX.

Rhythm	Total #	
	1976	1977
Ventricular Fibrillation	280	321
Asystole	146	140
Electromechanical Dissociation	49	87
Other *	69	64
Total	544	612

Table XXX - Continued

* Patients had rhythm by the time ECG obtained after initial CPR.

As in other series ventricular fibrillation was the most common rhythm.

In Table XXXI are shown the numbers of patients by initial rhythm who developed a blood pressure and rhythm sufficient enough to be moved from the various emergency rooms to the intensive care units. The percentages are the percent of patients with that initial rhythm admitted.

Table XXXI.

	# Admitted (% of pts. with that rhythm)	
	1976	1977
Ventricular Fibrillation	47(16.8%)	52(16.2%)
Asystole	4(2.7%)	10(7.1%)
Electromechanical Dissociation	2(4.1%)	14(16.1%)
Other	17(24.6%)	26(40.6%)
Total	70(12.9%)	102(16.7%)

Table XXXII shows the number of patients admitted after cardiac arrest and the number discharged alive plus the number of neurologic deficits in survivors.

Table XXXII. Cardiac Arrest Results.

	1976	1977
Total #	544	612
# Admitted to ICU or CCU	70(12.9%)	102(16.7%)
# Discharged alive	16(2.9%)	34(5.6%)
# Neurological deficit	1	6

When just the patients with ventricular fibrillation are examined, you can see that our resuscitation rates compare to areas without citizen CPR in a favorable sense. (Table XXXIII). However, in areas such as Seattle where they have citizens doing CPR, 50% of the time when paramedics arrive the results are 2-3 times as good.

Table XXXIII. Ventricular Fibrillation Results.

	Ventricular Fibrillation	
	1976	1977
Total # VF	280	321
# Admitted VF	47(17%)	52(16%)
Discharged alive VF	14(5%)	31(10%)

In our own system the survival more than doubles in the few instances when citizens are doing CPR when the paramedics arrive as is shown in Table XXXIV.

Table XXXIV.

	# Patients		Admitted %	
	1976	1977	1976	1977
No Citizen CPR	530	584	64(12%)	93(16%)
Citizen CPR	14	28	6(43%)	9(32%)

Hence to improve our resuscitation rate the essential ingredient is to train more citizens to do CPR. No matter how good paramedics are and how fast the system can respond, if something is not done in the first few minutes by bystanders the results will not improve significantly.

Table XXXV shows the mortality rates in the Dallas EMS District over the past several years. There has been a significant reduction in cardiac and total mortality rates.

Table XXXV.

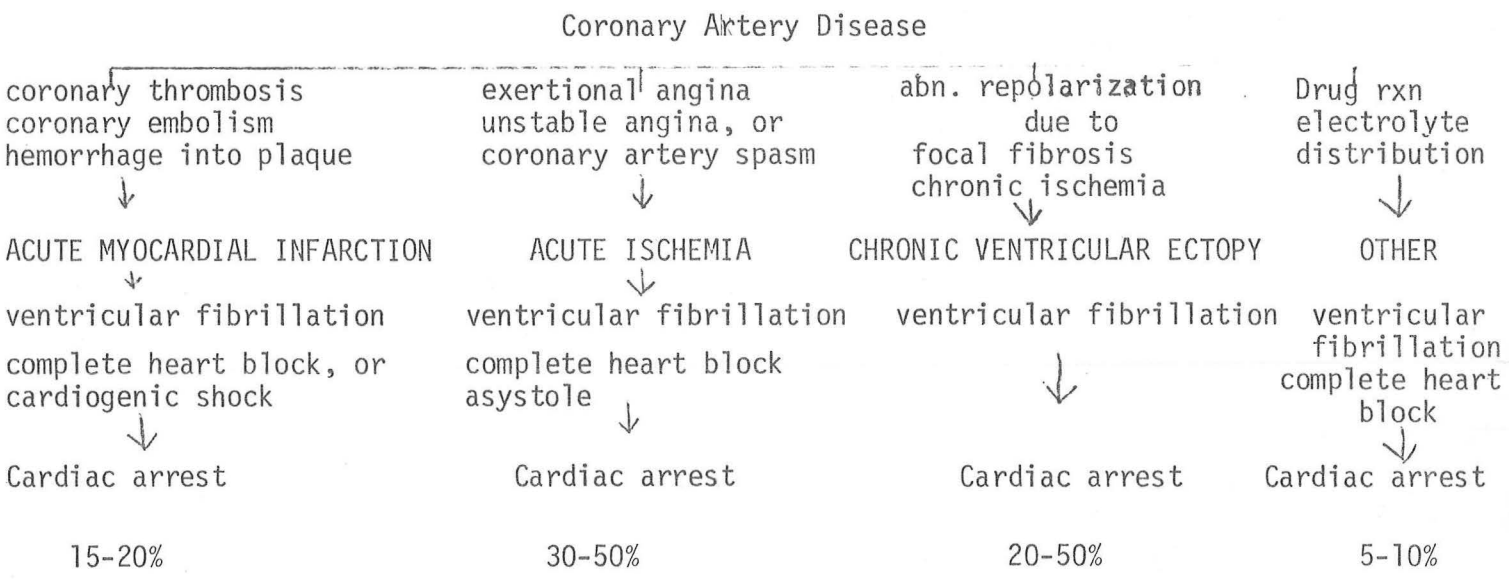
	1970	1971	1972+	1976++	1977
Total Population	1,635,422	1,673,304	1,759,186	1,882,950	1,914,630
All Deaths	12,581	12,732	13,209	12,944	13,249
Deaths/1000 Population	7.69	7.61	7.51	6.87	6.92
Cardiac Deaths	4,303	4,512	4,658	4,433	4,508
Cardiac Deaths/1000 Population	2.63	2.70	2.65	2.35	2.35

+Basic EMT system begun for 55% of population
++Paramedic system in operation for 60% of population

While EMS may have contributed to this reduction in some unmeasurable degree, the reduction was also contributed to by improved care, coronary artery bypass grafts, better nutrition, risk factor reduction and other factors as well.

A Model of Coronary Sudden Death

From the various data that has been presented there appears to be four mechanisms of sudden death in patients with coronary artery disease. The four mechanisms are acute myocardial infarction, acute ischemia, chronic ventricular ectopy, and other etiologies. A proposed model is shown below in Figure 15.



The incidence of transmural myocardial infarction in survivors is the same as the incidence in pathologic series suggesting that the incidence of infarction is low in sudden death. Moreover, most patients with infarction have a new occlusion of a coronary artery due to thrombosis, hemorrhage or embolus. Hence analysis of this data supports Herrick's (34) hypothesis that infarction is usually due to occlusions of a coronary artery. This does not support the hypothesis of Roberts and Buja (37) that infarction occurs first then secondary occlusion.

The evidence for the importance of acute ischemia comes from Friedman's (12) work and is summarized in the following tables XXXVI and XXXVII.

Table XXXVI. - Chronic Pathologic Findings in Coronary and Noncoronary Death Cases.

	Instantaneous Coronary Deaths	Sudden Coronary Deaths	Instantaneous and Sudden Non-Coronary Deaths
Number of Cases	25	34	16
Heart weight, average (range)	427	430	407
Chronic infarcts*			
Number			
0	11	17	16
1	9	14	0
2 or more	5	3	0
Site			
Anterior	3	4	0
Anterior and septal	0	1	0
Anterior and posterior	2	2	0
Posterior	5	8	0
Posterior and septal	4	2	0
Chronic myocardial fibrosis (diffuse)†			
Moderate	14	22	1
Severe	3	5	0
Coronary distribution pattern			
Balanced	17	22	8
Right dominant	5	10	4
Left dominant	3	2	4
Severely narrowed (>75%) coronary arteries‡			
0	2	2	7
1	3	6	5
2	4	7	4
3	10	12	0
4	6	7	0
Totally occluded coronary arteries§			
0	6	18	16
1	8	14	0
2‖	6	2	0
3‖	5	0	0
4	0	0	0
Arteries occluded			
Right coronary	12	11	0
Left main	1	1	0
Left anterior descending¶	13	1	0
Left circumflex	8	7	0
Recanalized vessels#			
Present	17	15	0
Functionally significant	13	11	0

Table XXXVII (12). Acute Pathologic Findings in Coronary and Noncoronary Death Cases and Activity.

	Instantaneous Coronary Deaths	Sudden Coronary Deaths	Instantaneous and Sudden Noncoronary Deaths
No. of Cases	25	34	16
Acute infarct			
No. of cases	0	7	0
Site			
Anterior	0	3	0
Anterior, septal	0	1	0
Posterior	0	1	0
Posterior, septal	0	2	0
Acute thrombosis (in original lumen)			
No. of cases	1	20	0
Artery			
Right coronary	0	7	0
Left main	0	1	0
Left anterior descending	1	10	0
Left circumflex	0	2	0
Acute thrombosis (in recanalized vessel)			
No. of cases	0	8	0
Intramural hemorrhage			
No. of cases	0	19	0
No. associated with thrombosis	-	18	-
Hemorrhage or hematoma in recanalized tissue			
No. of cases	4	2	0
Activity immediately prior to terminal episode			
Severe physical activity	10	1	0
Moderate physical activity	4	2	0
Sitting or reclining	9	23	7
Sleeping	2	6	0
Standing	1	5	1
Eating	0	0	1
Driving	0	0	7
Sexual intercourse	0	0	0
Defecation	1	0	0

As can be seen in Table XXXVI, the distribution of chronic coronary disease was not different between the instantaneous and sudden coronary deaths. However, in Table XXXVII there were marked differences in activity and acute pathologic changes. The activity level of the instantaneous coronary death group was more than the sudden deaths and pathologically there were no infarctions and very few acute coronary lesions suggesting that exertion triggered acute ischemia which caused instantaneous death. The role of coronary artery spasm in causing acute ischemia is unclear. There are many anecdotal cases of sudden death during acute spasm; however, or there are no definite pathologic changes with spasm and its incidence is hard to gauge. Dr. Hillis has written a review on the subject (89) and

will present a grand rounds on the subject in the near future.

The role of chronic ventricular ectopy is also unclear but there are many cases and series of patients who have recurrent ventricular tachycardia at rest or secondary to stimulation. A recent book edited by Narula (90) illustrates many cases.

Treatment of survivors of sudden death

The management of the survivors probably is dependent upon the mechanism of sudden death and treatment will be discussed by mechanism.

1. Myocardial infarction

If the patient survives sudden death due to acute myocardial infarction, his risks and prognosis is the same as any other patient with transmural myocardial infarction. Management long term should be routine. If the patient does not have arrhythmias after 48 hours, there is no evidence that antiarrhythmic therapy is required; however most cardiologists would leave the patient on chronic antiarrhythmics empirically.

2. Acute ischemia

The treatment of sudden death secondary to acute ischemia is two fold - you must treat the ischemia and give antiarrhythmias. The treatment of the ischemia can be by coronary artery bypass grafts, aneurysmectomy, a combination of the two or by medical therapy with nitrates and Beta blockers. Surgical therapy has some limited success in those patients with exertionally related sudden death. A review has recently been published by Harrison et al (91). No matter how the ischemia is treated, antiarrhythmic therapy with potent agents is mandatory and patients should avoid activities that would induce ischemia.

3. Chronic ventricular ectopy

Chronic ventricular ectopy is the most difficult to treat. Coronary artery bypass grafts in this group of patients has not been very rewarding as most patients have the same number of arrhythmias post-operatively as pre-operatively. Medical management should be attempted first then the patient should have Holter monitoring and exercise testing to evaluate the effectiveness of therapy. Table XXXVIII contains the drugs that are indicated or contraindicated in various settings (92).

Table XXXVIII(92). Effectiveness of Drugs Related to Clinical Setting.

VT Setting	(Possibly)Useful	(Possibly) Contraindicated (or Useless)
Acute myocardial infarction (93,94) (Ref. 94 contains a detailed bibliography on conventional antiarrhythmic drugs in coronary artery disease)	Lidocaine Quinidine Procainamide (Propranolol) (Diphenylhydantoin)(96) Aprindine(97,98) (Verapamil)(95,99) Disopyramide(100) Amiodarone(101) Bretylium(102)	(Aprindine in dogs)(95)
Chronic coronary artery disease (93,94,103-105)	Diphenylhydantoin Procainamide β-Blockers Quinidine Digitalis preparation (107) Aprindine (108) (Verapamil)(99,109) Disopyramide (100) Amiodarone (101) Tocainide (110)	(Diphenylhydantoin)(108)
Digitalis toxicity (104,111)	Diphenylhydantoin (96) Lidocaine (96) Procainamide (113) β-Blockers (112) Verapamil (99) Aprindine (114) Carbamazepine (115)	(β-Blockers)(112)
QT interval prolongation(116)	β-Blockers (117-120) Diphenylhydantoin (116,119) Digitalis preparation (121) Carbamazepine (123) Isoproterenol (123,124)	(Procainamide) (Quinidine)
Torsade de pointes (124)	Isoproterenol (123,124)	(Lidocaine)(124) (Procainamide)(124) (Quinidine)(124)
Mitral valve prolapse	Propranolol Procainamide Quinidine Digitalis preparation Diphenylhydantoin(125,126) Aprindine(108,127) Tocainide(110)	(Psychotropic agents)(124)

Table XXXVIII Continued

VT due to atrial fibrillation in Wolff-Parkinson-White syndrome (128-130)	Lidocaine(131) Procainamide(132,134-135) Quinidine(132,134-135) Propranolol(132) Aprindine(136) Amiodarone(137,138)	Digitalis (132,133)
Idiopathic,miscellaneous (93,103,104,105,140)	Quinidine Procainamide β-blockers Diphenylhydantoin Digitalis preparation Disopyramide (100) Aprindine (108) Amiodarone (101) Tocainide (110)	

Selection of antiarrhythmias at first should be empiric to suppress both PVC's and to eliminate couplets and ventricular tachycardia. Recurrent episodes should probably require electrophysiologic testing as outlined in Narula's textbook (190).

New methods may include "smart" pacemakers that analyze the rhythm and either breaks the ventricular tachycardia by pacing competetively at a rate less than tachycardia or by giving a burst of pacing faster than the tachycardia. In the future automatic implantable defibrillators may be implanted in patients with recurrent problems. Surgical mapping techniques are also being developed to find and resect the zone causing the ectopy and are reviewed in Narula's textbook.(90)

Addendum - New standards for resuscitation from American Heart Association.

Management of Specific Types of Cardiac Arrest

Ventricular Fibrillation

When the patient develops ventricular fibrillation while being monitored electrocardiographically (witnessed ventricular fibrillation), and when a defibrillator is immediately available, the initial therapy is nonsynchronized direct current countershock (defibrillation), 200-300 joules delivered energy. If successful defibrillation is accomplished promptly, the administration of sodium bicarbonate may be unnecessary.

In the management of pre-hospital cardiac arrest, it is most common for the patient to be in ventricular fibrillation upon arrival of the rescue team (unwitnessed ventricular fibrillation). The first step in resuscitation is institution of CPR. If this has been done within two minutes of cardiac arrest onset and the presence of ventricular fibrillation has been confirmed (preferably using paddle-electrodes and a battery-powered defibrillator with an oscilloscope), defibrillation should be attempted with 200-300 joules delivered energy. In the usual case, however, cardiac arrest has been present for several or more minutes before any rescue efforts are attempted. In that case CPR should be instituted and continued for two minutes before defibrillation is attempted. If the first countershock of 200-300 joules delivered energy is not successful, a second countershock of 200-300 joules delivered energy should be delivered as soon as possible. If the second countershock is not successful, then:

1. Establish an effective airway: endotracheal intubation is preferable.

2. Establish an intravenous line (endotracheal drug administration may be a simple and effective alternative).

3. Administer sodium bicarbonate, 1 m.eq/kg.

4. Administer 0.5 to 1.0 mgm or 5.0ml of 1:10,000 epinephrine IV, unless catecholamine excess is suspected.

5. Defibrillate with 300-400 joules delivered energy.

Following defibrillation one of four rhythms may result:

1. Supraventricular rhythm with a normal or rapid ventricular rate. This may be a sinus rhythm, but is often atrial fibrillation. When the ventricular rate is not excessive, this is the most desirable result and it has been associated with a more favorable prognosis. It is unlikely to result unless both hypoxia and acidosis have been corrected. Once this type of rhythm has been established, an intravenous bolus of

idocaine should be given, followed by a lidocaine infusion.

A potentially dangerous situation may result when the ventricular rate following defibrillation is rapid (greater than 100/min). This is often associated with hypertension. A possible cause is excess catecholamine release or excessive use of epinephrine. The increase in both heart rate and in impedance to left ventricular ejection results in an elevation in myocardial oxygen demand. The net result is frequently the precipitation of ventricular asystole (VA) or VF. In the presence of a persistent rapid supraventricular rate and hypertension, the use of propranolol may be helpful. Lidocaine should also be administered as described previously.

2. A bradyarrhythmia, commonly either junctional escape rhythm or ventricular escape rhythm (idioventricular rhythm). These two rhythms may be impossible to distinguish since atrial activity is often not evident and the QRS complex may appear wide With proper ventilation and correction of acidosis, the QRS complex in junctional escape rhythm may become narrow. Either type of rhythm in association with hemodynamic or electrical instability may be associated with complete atrioventricular block. The appropriate therapy at this time would be:

   a. Evaluate adequacy of ventilation, since hypoxia may be contributing to this arrhythmia.

   b. Repeat epinephrine, or institute an epinephrine drip.

   c. If a more rapid supraventricular rhythm does not result, administer atropine. Atropine is more likely to be effective if P-waves are evident on the electrocardiogram monitor, and result in the return of normal atrioventricular conduction. In the absence of evident sinus node activity, atropine may relieve sinoatrial block and restore sinus rhythm.

   d. If these measures are unsuccessful, a temporary pacemaker may be necessary. In the prehospital setting, or when immediate insertion of a pacemaker is not feasible, a cautious use of intravenous isoproterenol may be effective. This may result in the restoration of sinus rhythm with normal atrioventricular conduction, or in the acceleration of the escape pacemaker, thereby improving cardiac output. The infusion rate should be adjusted to maintain a ventricular rate of 60 to 70/min. If a stable supraventricular rhythm is obtained, isoproterenol can usually be discontinued.

3. Ventricular asystole. This may be an indication of uncorrected hypoxia and/or acidosis, or of extensive myocardial damage. The following measures should be taken:

   a. Evaluate adequacy of ventilation. It may be necessary, for example, to suction the patient, or to correct faulty ventilation technique (e.g., such as the lack of a proper face mask seal resulting in an oxygen leak, or improper head position during mouth-to-mouth ventilation). When inadequate ventilation is suspected in an intubated patient, the position of the tube should be checked.

   b. Evaluate external cardiac compression.

   c. Give bicarbonate. If electrical activity is not reestablished,

   d. Give epinephrine. If electrical activity is not reestablished,

   e. Give calcium chloride.

4. Ventricular fibrillation. Persistence of ventricular fibrillation after attempted defibrillation also may be an indication of uncorrected hypoxia and/or acidosis, or of extensive myocardial damage. In addition, specific causes of VF such a catecholamine excess, hyperkalemia and other electrolyte disturbances, digitalis intoxication, etc., need to be considered since successful resuscitation may depend upon correction of the precipitating abnormality. The following steps should be taken:

   a. Evaluate adequacy of ventilation.

   b. Evaluate external cardiac compression.

   c. Repeat dose of sodium bicarbonate, unless arterial blood gases are available and indicate this is unnecessary.

   d. Repeat dose of epinephrine.

   e. Repeat defibrillation.

   f. If ventricular fibrillation persists, give bretylium 5 mg/kg IV push and then defibrillate. If ventricular fibrillation persists in spite of this dose and countershock occurs, the dose can be increased to 10 mg/Kg and repeated at 15-30 minute intervals until a maximum dose of 30 mg/Kg has been given.

Ventricular Asystole

When cardiac arrest has resulted from ventricular asystole (or when this has occurred as the end result of ventricular fibrillation or electromechanical dissociation) a severe metabolic deficit and/or extensive myocardial damage may be present. It is possible also that high levels of parasympathetic tone can result in cessation of both supraventricular and ventricular pacemaker activity.

In the presence of ventricular asystole the prognosis for resuscitation is poor. In addition to beginning CPR, inserting an endotracheal tube or esophageal airway for optimal ventilation, and starting an intravenous infusion, the following steps should be taken:

1. Administer sodium bicarbonate.

2. Give epinephrine IV. If a rhythm is not restored, then:

3. Administer atropine 1.0 to 2.0 mg IV (This is empiric and is based on the observation that a supraventricular rhythm may occasionally be restored in this setting and the prognosis is otherwise so poor).

4. Administer calcium chloride IV.

5. If a rhythm has not been restored, repeat the original dose of bicarbonate, and:

6. Administer epinephrine by intracardiac injection (if rescue personnel have proper training in this technique).

Electromechanical Dissociation

In electromechanical dissociation, there is evidence of organized electrical activity on the electrocardiogram, but failure of effective myocardial contraction. Although the mechanism is not completely understood, it may result from failure in the calcium transport system. This ion is essential for coupling of the electrical event with mechanical contraction. The occurrence of electromechanical dissociation carries a grave prognosis. It is important to recognize that pericardial tamponade may mimic electromechanical dissociation and yet may be successfully treated by pericardiocentesis. Myocardial rupture may also be confused with electromechanical dissociation and has been successfully treated with surgical repair
In addition to CPR with optimal ventilation, the following measures may be employed.

1. Administer two ampules of sodium bicarbonate.

2. Give epinephrine IV. If ineffective,

3. Administer calcium chloride IV.

4. If effective contractions have not been restored, repeat the original dose of bicarbonate and, if IV epinephrine was unsuccessful,

5. Administer epinephrine by endotracheal or intracardiac injection.

   If electromechanical dissociation persists,

6. An intravenous infusion of isoproterenol IV may be started.

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