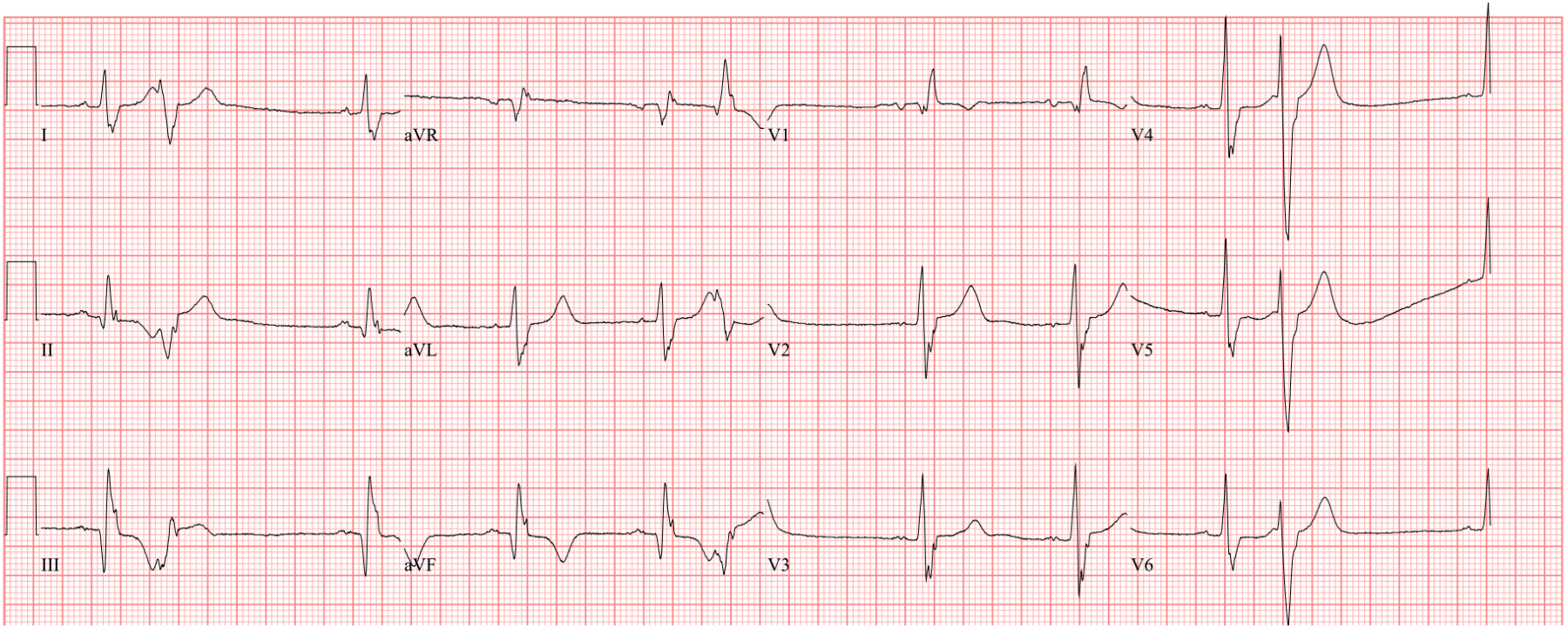
Utilizing ECG to Stratify SCD Risk in CHD Patients with LVEF>35%

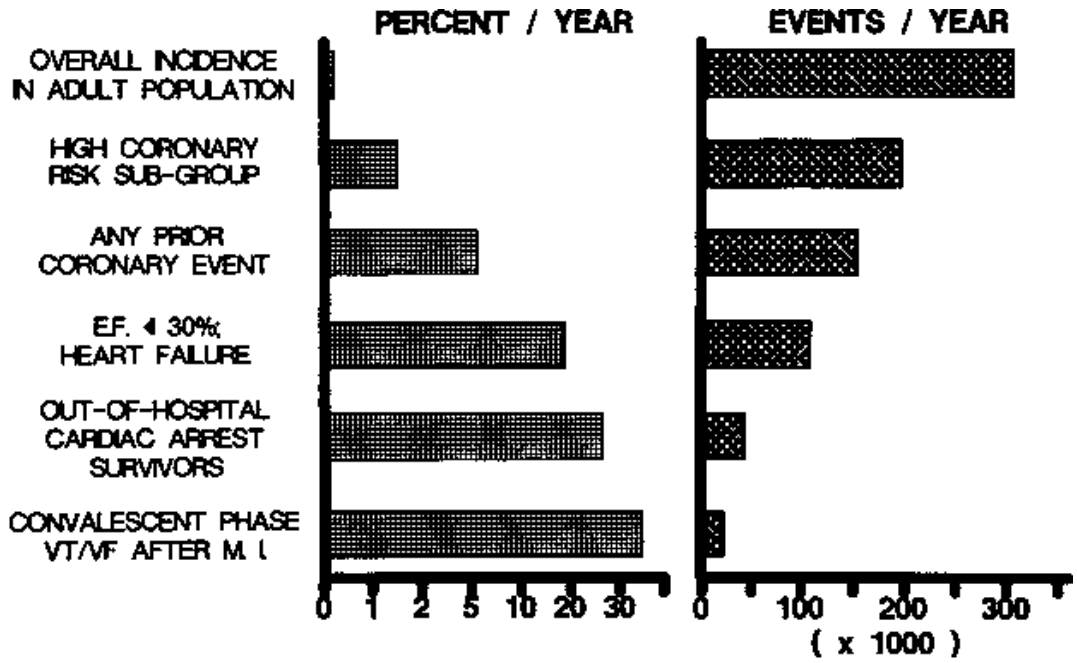
Min Soo Cho
Asan Medical Center
University of Ulan, College of Medicine

Case



- 76/M
- Recent infarction with LVEF 42%
- Does the patient require ICD?

Why LVEF >35% important?



- Should be the priority for VT/VF risk assessment
  - Highest number of those at risk of VT/VF
  - Currently non-protected by guideline based on LVEF value

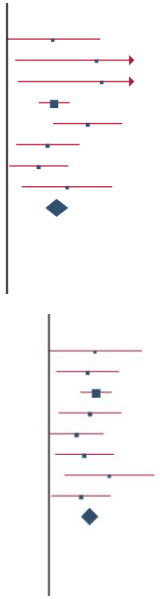
Circulation 1992;85:I2

Current risk stratification

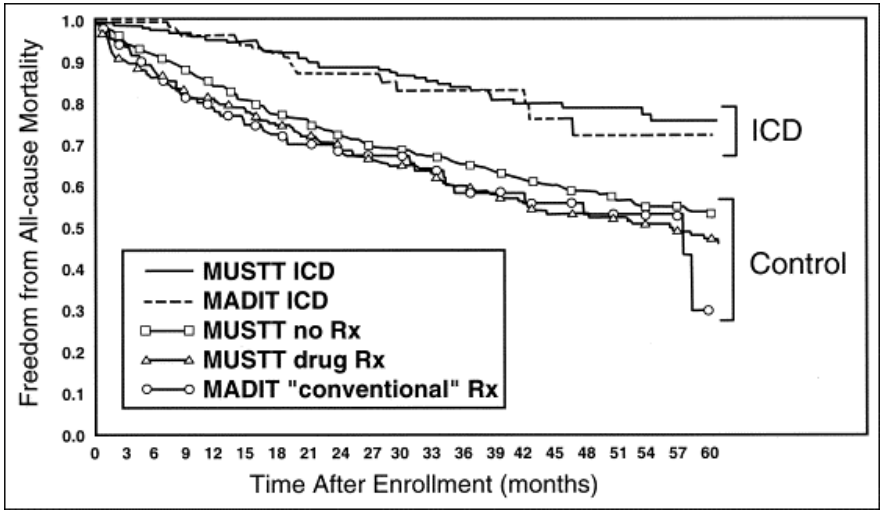
Meta analysis for LGE

1.1.2 Studies With Nonischemic Cardiomyopathy						
Assomull (17)	5	35	2	66	2.9%	5.33 [0.98, 29.08]
Iles (18)	9	31	0	30	1.0%	25.76 [1.42, 465.99]
Leyva (19)	3	20	0	77	0.9%	31.00 [1.53, 627.81]
Gulati (11)	42	142	23	330	27.2%	5.61 [3.21, 9.78]
Neilan (20)	34	81	3	81	5.5%	18.81 [5.47, 64.65]
Muller (21)	16	94	4	91	6.5%	4.46 [1.43, 13.92]
Perazzolo-Marra (22)	17	76	5	61	7.5%	3.23 [1.12, 9.33]
Masci (23)	6	61	2	167	3.2%	9.00 [1.76, 45.90]
Subtotal (95% CI)		**540**		**903**	**54.6%**	**6.27 [4.15, 9.47]**
Total Events	132		39			
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 7.26$, df = 7 (P = 0.40); $I^2 = 4\%$						
Test for Overall Effect: Z = 8.72 (P < 0.00001)						

1.2.2 Studies With Mean EF >30%							
Assomull (17)	5	35	2	66	2.9%	5.33 [0.98, 29.08]	2006
Klem (10)	21	84	4	53	6.6%	4.08 [1.32, 12.67]	2012
Gulati (11)	42	142	23	330	27.2%	5.61 [3.21, 9.78]	2013
Muller (21)	16	94	4	91	6.5%	4.46 [1.43, 13.92]	2013
Demirel (16)	27	62	7	32	8.8%	2.76 [1.04, 7.32]	2014
Almehmadi (27)	45	248	4	70	7.5%	3.66 [1.27, 10.55]	2014
Masci (23)	6	61	2	167	3.2%	9.00 [1.76, 45.90]	2014
Perazzolo-Marra (22)	17	76	5	61	7.5%	3.23 [1.12, 9.33]	2014
Subtotal (95% CI)		**802**		**870**	**70.0%**	**4.48 [3.17, 6.33]**	
Total Events	179		51				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.85$, df = 7 (P = 0.90); $I^2 = 0\%$							
Test for Overall Effect: Z = 8.48 (P < 0.00001)							



MUSTT and MADIT trial



- LGE on MRI
- EPS in MUSTT trial
- Risk assessment based on the ECGs were not well evaluated

J Am Coll Cardiol Img2016;9:1046
Am J Cardiol 2000;86:1214

서울아산병원 Asan Medical Center

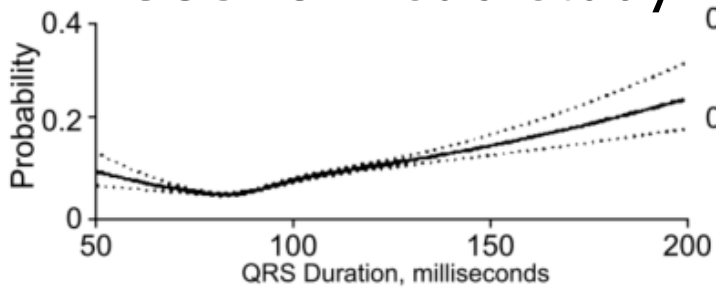
울산대학교

Table. Summary of Noninvasive Risk-Stratification Techniques for Identifying Patients With Coronary Artery Disease Who Are At Risk for Sudden Cardiac Death (SCD)

Technique	Conclusion
Left ventricular ejection fraction (LVEF)	Low LVEF is a well-demonstrated risk factor for SCD.
	Although low LVEF has been effectively used to select high-risk patients for application of therapy to prevent sudden arrhythmic death, LVEF has limited sensitivity: the majority of SCDs occur in patients with more preserved LVEF.
Electrocardiogram (ECG)	
QRS duration	Most retrospective analyses show increased QRS duration is likely a risk factor for SCD.
	Clinical utility to guide selection of therapy has not been tested.
QT interval and QT dispersion	Some retrospective analyses data show that abnormalities in cardiac repolarization are risk factors for SCD.
	Clinical utility to guide selection of therapy has not yet been tested.
Signal-averaged ECG (SAECG)	An abnormal SAECG is likely a risk factor for SCD, based predominantly on prospective analyses.
	Clinical utility to guide selection of therapy has been tested, but not yet demonstrated.
Short-term heart rate variability (HRV)	Limited data link impaired short-term HRV to increased risk for SCD.
	Clinical utility to guide selection of therapy has not yet been tested.
Long-term ambulatory ECG recording (Holter)	
Ventricular ectopy and NSVT	The presence of ventricular arrhythmias (VPBs, NSVT) on Holter monitoring is a well-demonstrated risk factor for SCD.
	In some populations, the presence of NSVT has been effectively used to select high-risk patients for application of therapy to prevent sudden arrhythmic death. This may also have limited sensitivity.
Long-term HRV	Low HRV is a risk factor for mortality, but likely is not specific for SCD.
	Clinical utility to guide selection of therapy has been tested, but not demonstrated.
Heart rate turbulence	Emerging data show that abnormal heart rate turbulence is a likely risk factor for SCD.
	Clinical utility to guide selection of therapy has been tested, but not yet demonstrated.
Exercise test/functional status	
Exercise capacity and NYHA class	Increasing severity of heart failure is a likely risk factor for SCD, although it may be more predictive of risk for progressive pump failure.
	Clinical utility to guide selection of therapy has not yet been tested.
Heart rate recovery and recovery ventricular ectopy	Limited data show that low heart rate recovery and ventricular ectopy during recovery are risk factors for SCD.
	Clinical utility to guide selection of therapy has not yet been tested.
T-wave alternans	A moderate amount of prospective data suggests that abnormal T-wave alternans is a risk factor for SCD.
	Clinical utility to guide selection of therapy has been evaluated, but the results to date are inconsistent.
Baroreceptor sensitivity (BRS)	A moderate amount of data suggests that low BRS is a risk factor for SCD.
	Clinical utility to guide selection of therapy has not yet been tested.

QRS duration

GUSTO-1 sub-study



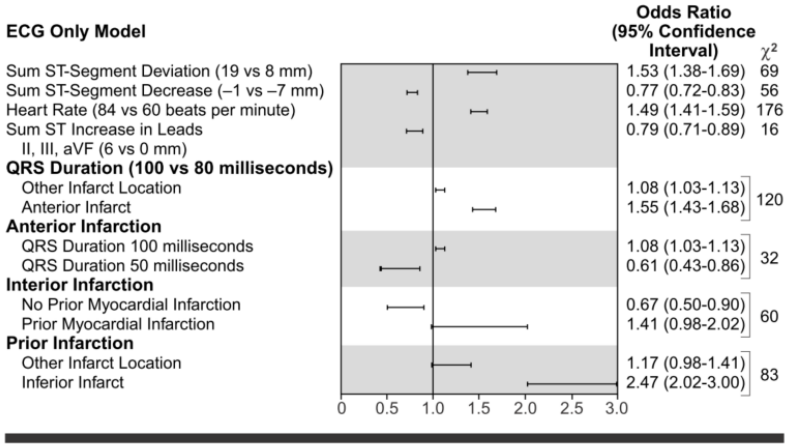
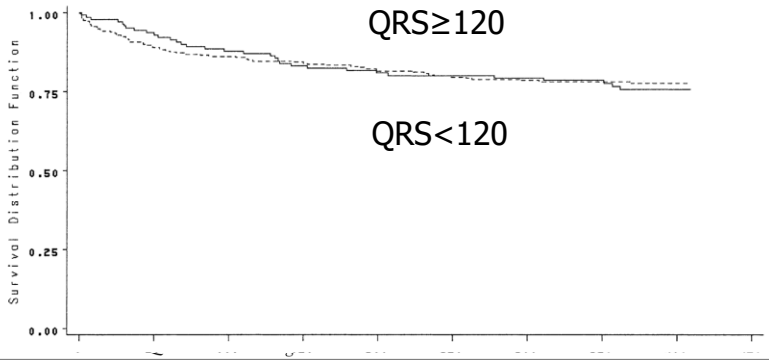


Figure 2.—Multivariable odds ratios and 95% confidence intervals for initial electrocardiographic (ECG) predictors of 30-day mortality. All *P* values are the same (<.001). Wald χ^2 values are given for the statistical significance of each factor after adjustment for all others listed.

Pain FREE Rx II



QRS Cutoff (ms)	False Positives (n)	True Positives (n)	True Negatives (n)	False Negatives (n)	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
80	303	90	33	5	95	10	23	87
90	271	82	65	13	86	19	23	83
100	198	54	138	41	57	41	21	77
110	168	46	168	49	48	50	21	77
120	108	32	228	63	34	68	23	78
130	92	26	244	69	27	73	22	78
140	56	18	280	77	19	83	24	78
150	43	17	293	78	18	87	28	79
160	13	8	323	87	8	96	38	79
170	12	6	324	89	6	96	33	78
180	2	2	334	93	2	99	50	78
190	1	1	335	94	1	99	50	78

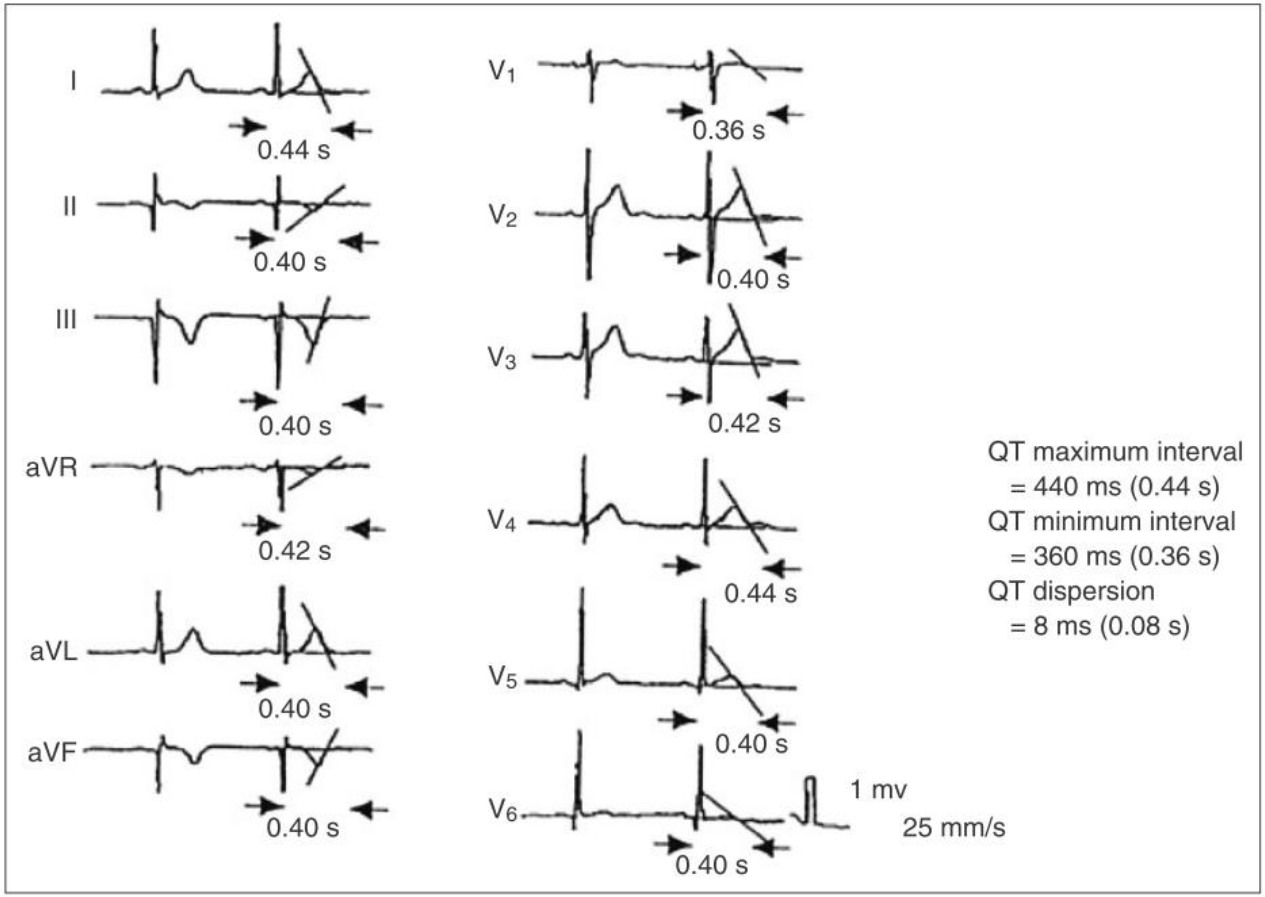
- There is little evidence that increased QRS duration associated with an increased SCD
- Predictive value of QRS duration itself was limited

서울아산병원 Asan Medical Center

JAMA 1998;279:387
JACC 2005;46:310

울산대학교

QT interval & QT dispersion



- QT dispersion = QTmax – QTmin
- Non-invasive measurement of inhomogeneity in ventricular repolarization

J Arrhythmia 2006; 22: 209

QT dispersion

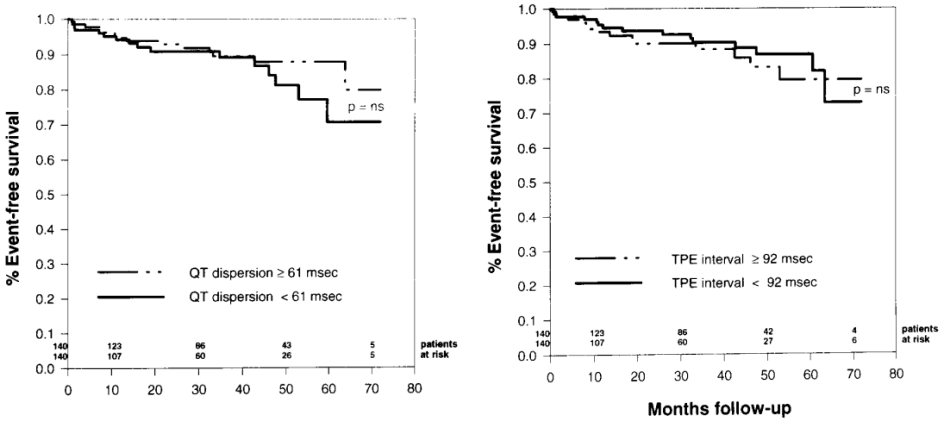
AIREX sub-study

Table 1 QT interval and QT dispersion measurements according to mortality status and the electrocardiographic presence of bundle branch block

	Survivors (n=320)	Deceased (n=181)	*P* value
Mean QT (ms)	382·0 ± 44·7	385·3 ± 44·9	0·42
Mean QTc (ms)	431·8 ± 33·4	447·2 ± 40·2	<0·001
QT dispersion (ms)	82·7 ± 34·3	92·0 ± 38·5	0·005
QTc dispersion (ms)	93·1 ± 35·9	105·7 ± 42·7	<0·001
	Patients without bundle branch block n=467	Patients with bundle branch block n=34	
Mean QT (ms)	381·8 ± 43·6	402·1 ± 55·8	0·01
Mean QTc (ms)	435·1 ± 35·5	469·1 ± 39·3	<0·001
QT dispersion (ms)	85·6 ± 35·7	91·6 ± 40·8	0·41

Mean ± SD.

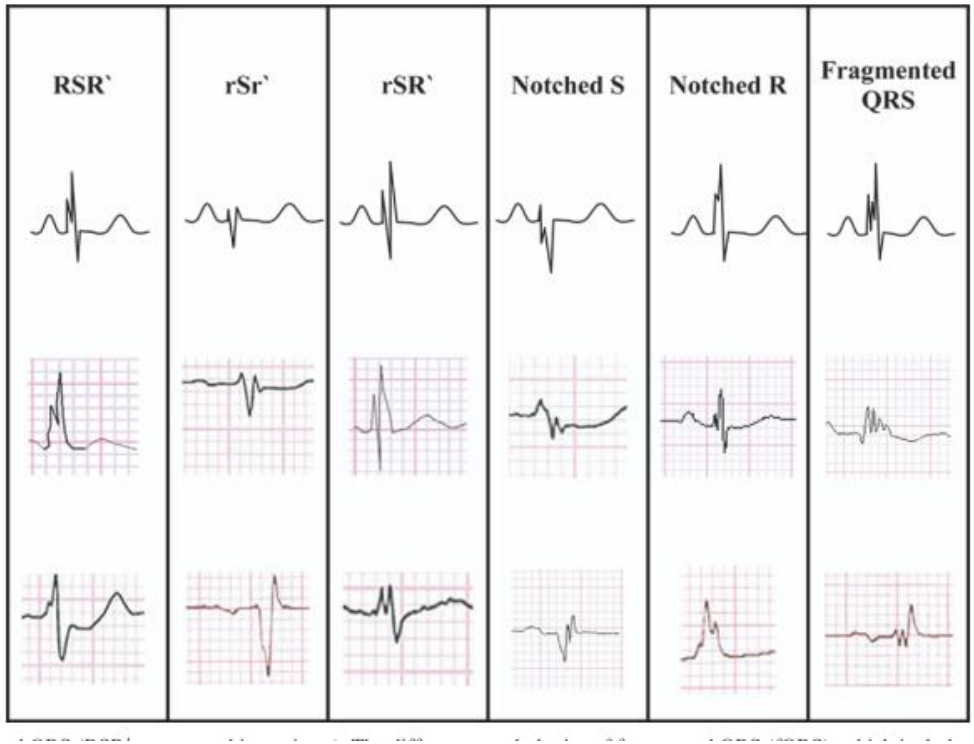
VA registry

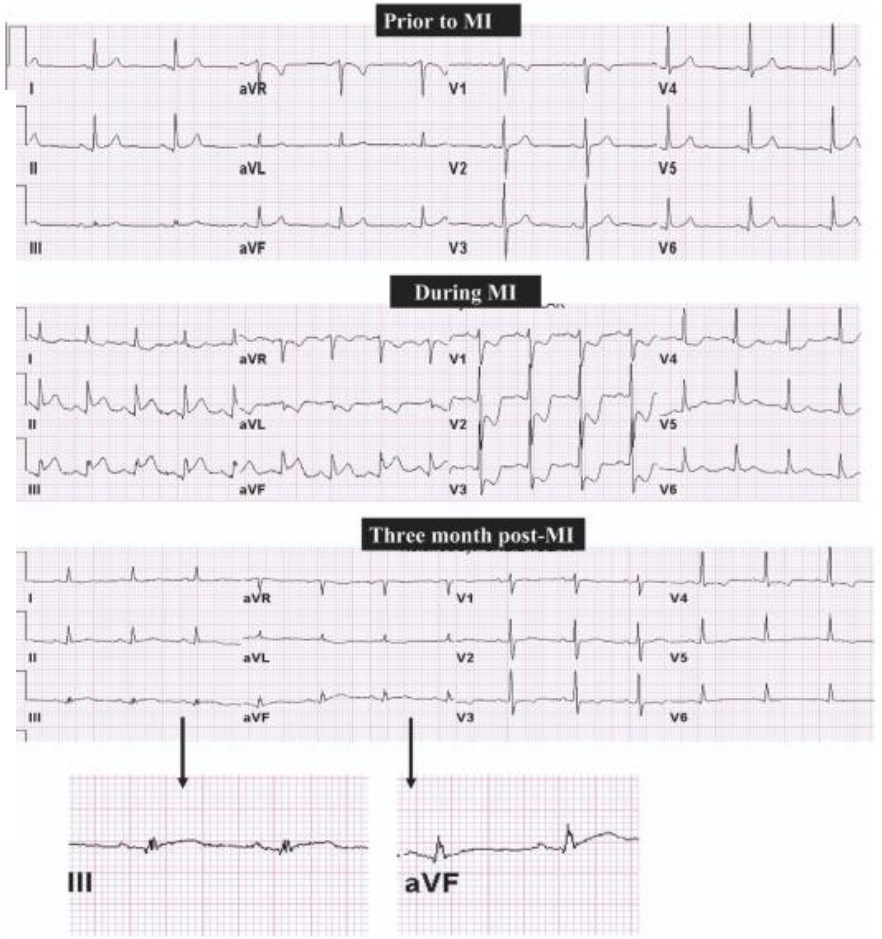


- Relationship between prolonged QT interval and QT dispersion to the SCD showed varying results
  - Inter-observer variability or wide overlaps in QT measurement
  - Genetic and racial factors may also relevant

Eur Heart J 1999; 20: 1158
Circulation 1998;97:2543

QRS fragmentation



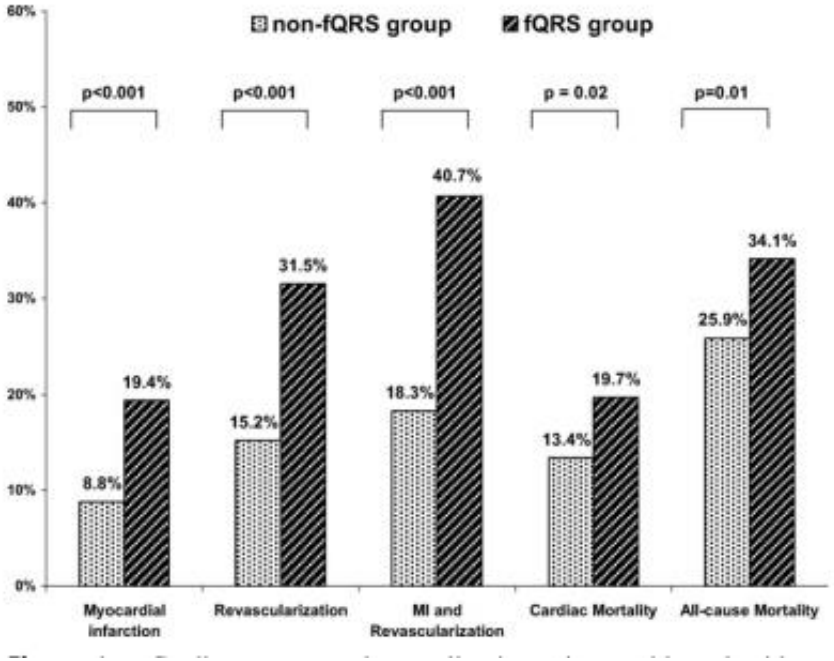


- Additional R wave (R') or notching in the nadir of S, notching of R, more than one R' (fragmentation)
- Represent the conduction delay caused by regional myocardial scar

Heart Rhythm 2007;4:1385

QRS fragmentation

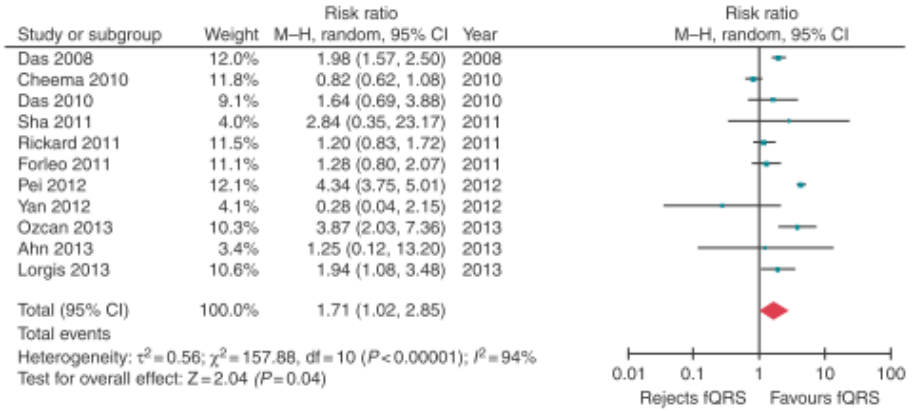
Clinical outcomes



LV aneurysm

Total Number of Patients Studied (N = 330)	LVA Present (N = 110)	LVA Absent (N = 220)[a]
Fragmented QRS present	55	11
(N = 66)	(True-positive)	(False-positive)
Fragmented QRS absent	55	209
(N = 264)	(False-negative)	(True-negative)

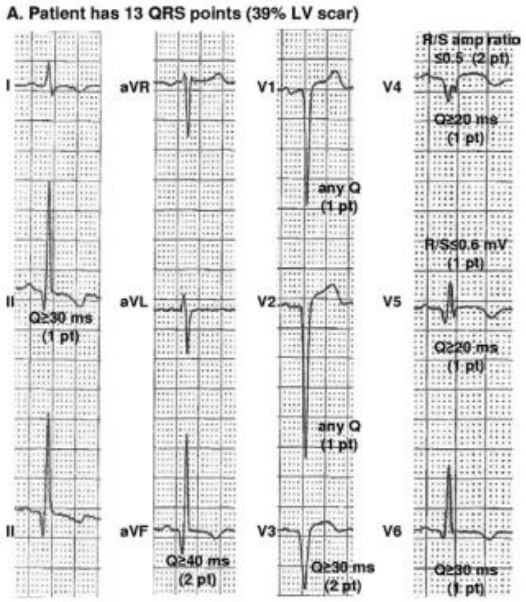
PPV 83.3%; NPV 79.2%

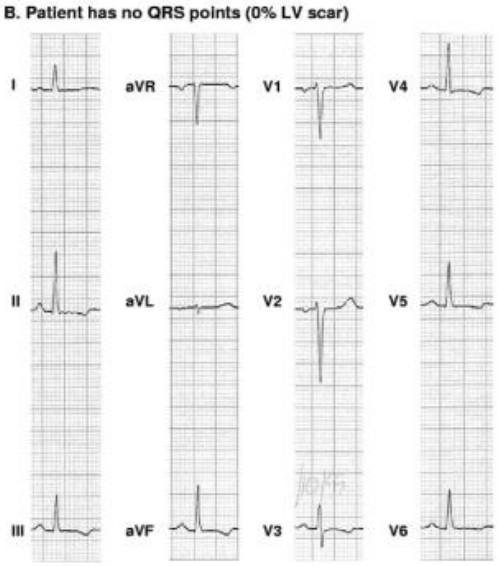


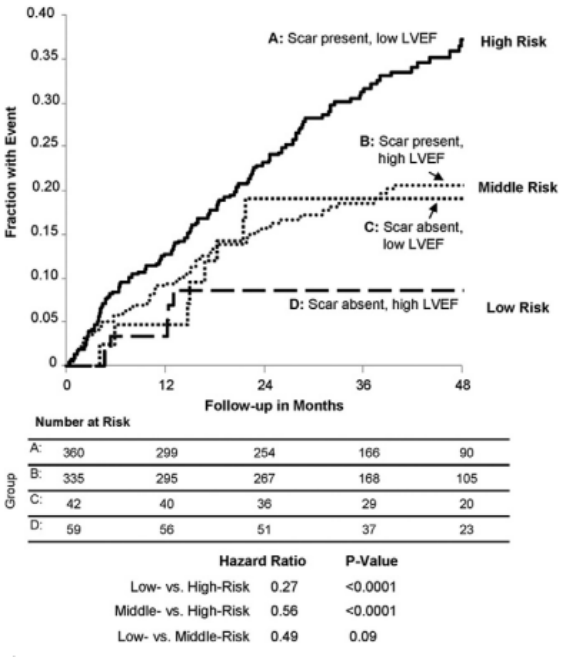
- fQRS is a strong independent predictor of major cardiovascular events
- It also associated with LV aneurysm, prior myocardial infarction, or perfusion abnormality after revascularization

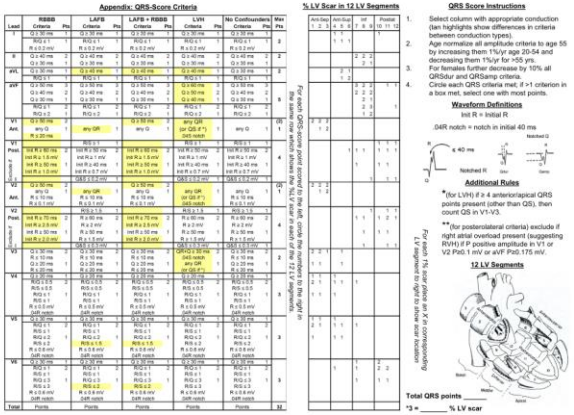
Heart Rhythm 2007;4:1385
Ann Noninvasive Electrocardiol 2006;11:132
Europace 2015;17:969

QRS scoring



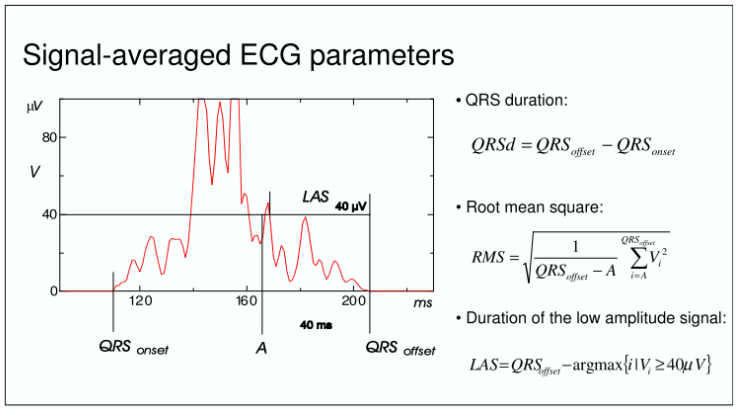






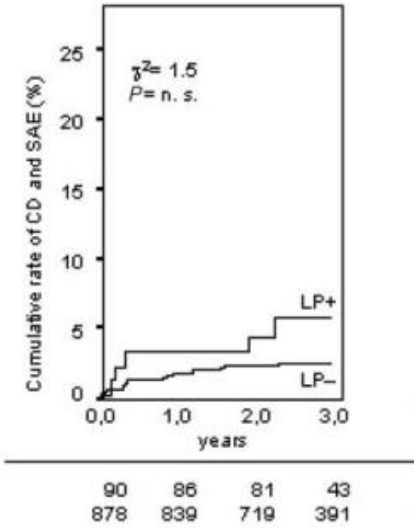
- ECG scoring to quantify myocardial scar
- Quantification of substrate for the reentrant tachycardia
- SCD-HeFT population
  - Scar presence = LVEF <25%

Signal-averaged ECG



Predictor	Arrhythmic Death/Cardiac Arrest χ^2	Arrhythmic Death/Cardiac Arrest P	Cardiac Death χ^2	Cardiac Death P
Continuous variables				
Filtered QRS duration	29.2	<0.001	34.0	<0.001
RMS voltage	14.3	0.004	17.0	<0.001
Duration of LAS	0.3	0.59	0.2	0.62
Dichotomous variables				
Filtered QRS duration (>114 vs ≤114 ms)	23.1	<0.001	20.8	<0.001
RMS voltage (<20 vs ≥20 μV)	0.3	0.59	0.1	0.73
Duration of LAS (<38 vs ≥38 ms)	1.6	0.21	0.3	0.58

LAS indicates low-amplitude signals.



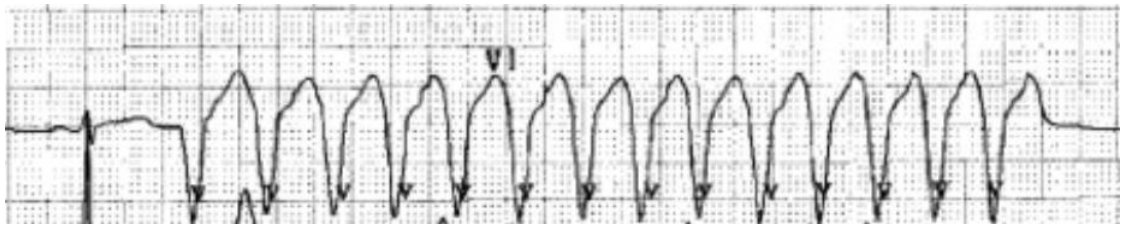
- Identify the late potential using amplified high-resolution ECG
- Associated with mortality, cardiac arrest, and VT inducibility
- Good NPV but low PPV
- Prognostic value has become less clear in PCI era

서울아산병원 Asan Medical Center

Computers in Cardiology 2002;29:297
Circulation. 2001;104:436
Eur Heart J. 2005;26:755

울산대학교

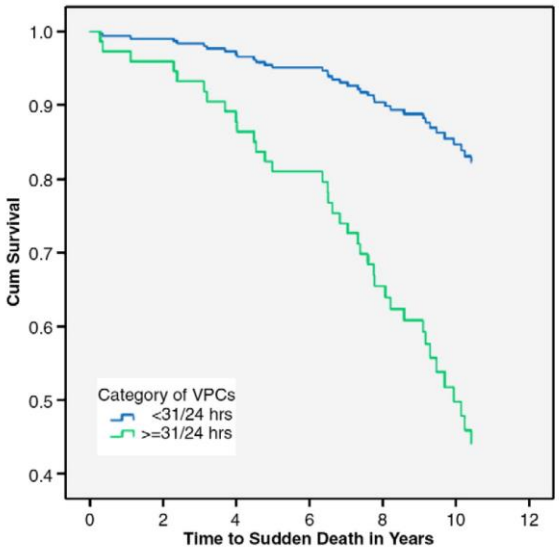
Non-sustained VT



FINGER registry

	EF ≤ 35% (n = 226)		EF > 35% (n = 1904)	
	SCD (n = 17)		SCD (n = 35)	
	HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
Multivariable analysis[a]				
NsVT	2.1 (0.7–6.7)	0.2010	3.5 (1.5–8.2)	0.0021
VPCs > 10/h	1.9 (0.7–5.4)	0.3322	1.2 (0.5–3.1)	0.7345
SDNN < 70 ms	1.3 (0.5–3.4)	0.6148	1.5 (0.7–3.4)	0.3074
SDNN (continuous)	1.00 (0.98–1.02)	0.7733	0.99 (0.97–1.00)	0.0292
ln VLF < 5.3	0.8 (0.2–3.9)	0.7996	2.7 (1.0–7.1)	0.0505
ln VLF (continuous)	1.26 (0.75–2.11)	0.3726	0.62 (0.46–0.82)	0.0008
ln LF < 3.85	0.7 (0.2–3.4)	0.6979	2.6 (0.9–7.9)	0.0826
ln LF (continuous)	1.24 (0.79–1.95)	0.3450	0.63 (0.50–0.81)	0.0002
TS (≤2.5 ms/RRI)	1.0 (0.4–2.1)	0.9310	4.7 (2.3–9.8)	0.0001
TS (continuous)	1.04 (0.89–1.21)	0.6418	0.77 (0.67–0.88)	0.0001
DFA (α_1 < 0.75)	1.0 (0.4–2.7)	0.5123	2.7 (1.3–5.7)	0.0088
DFA (continuous)	1.53 (0.13–17.4)	0.7317	0.26 (0.06–1.10)	0.0673
QRS ≥ 120 ms	0.9 (0.3–3.1)	0.9843	3.2 (1.4–7.3)	0.0039
QRS (continuous)	1.00 (0.98–1.02)	1.0000	1.00 (1.00–1.00)	0.4845

CHS study



- Non-sustained VT or frequent PVCs are useful predictor in patients with LVEF > 35%
- Routine use for assessing SCD risk is limited for low sensitivity and specificity

서울아산병원 Asan Medical Center

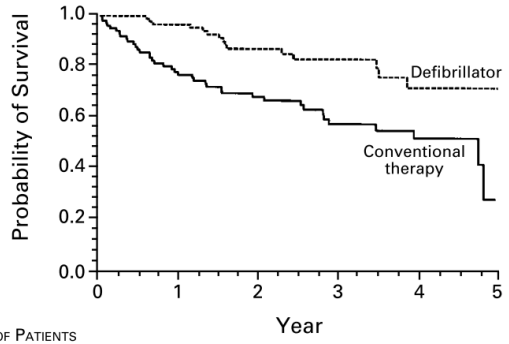
Eur heart J 2005;26:762
J electrocardiol 2010;43:251

울산대학교

Non-sustained VT

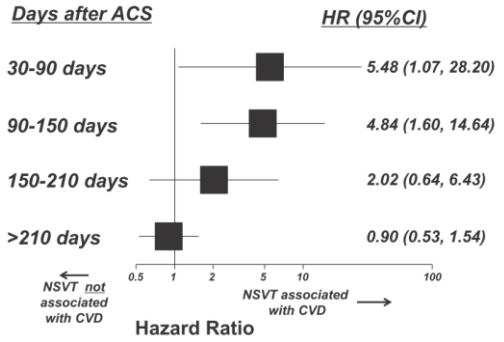
MADIT trial

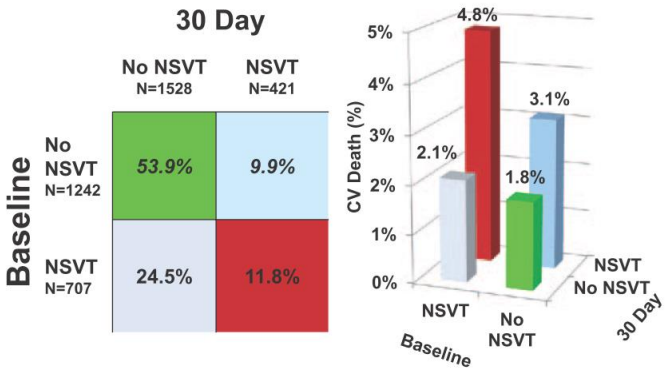
Methods Over the course of five years, 196 patients in New York Heart Association functional class I, II, or III with prior myocardial infarction; a left ventricular ejection fraction ≤0.35; a documented episode of asymptomatic unsustained ventricular tachycardia; and inducible, nonsuppressible ventricular tachyarrhythmia on electrophysiologic study were randomly assigned to receive an implanted defibrillator (n = 95) or conventional medical therapy (n = 101). We used a two-sided sequential design with death from any cause as the end point.



No. of Patients						
Defibrillator	95	80	53	31	17	3
Conventional therapy	101	67	48	29	17	0

PLATO sub-study





- MADIT trial demonstrate the NSVT or inducible VT benefited from the ICD therapy
- PLATO trial sub-study, 2,866 patients with 7 –day Holter at acute stage and convalescent phase (30 days)

N Engl J Med 1996;335:1933
Circ Arrhythm Electrophysiol. 2016;9:e002951

HRV

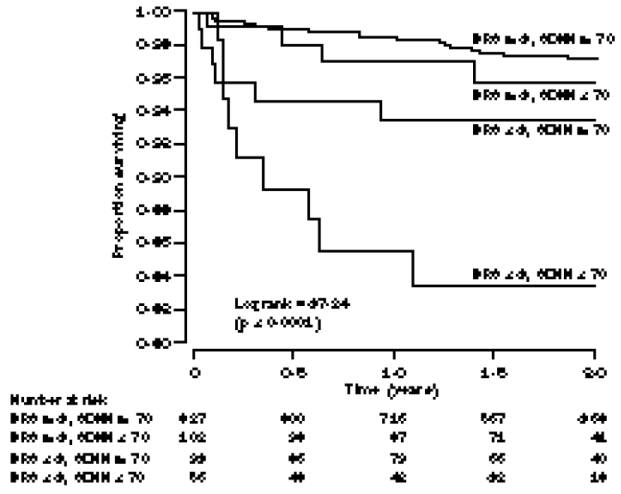


Figure 1: **Kaplan-Meier survival curves for total cardiac mortality according to BRS, SDNN, and their combination**
p value refers to differences in event rates between subgroups.

	Relative risk (95% CI)	p
Model including BRS		
LVEF		
35–50%	2·1 (0·90–4·69)	0·08
<35%	4·7 (2·04–10·9)	0·0003
BRS (ms per mm Hg)		
3·0–6·1	1·7 (0·81–3·69)	0·15
<3·0	2·8 (1·24–6·16)	0·01
⩾10 VPC/h	1·8 (0·94–3·46)	0·07
Model including SDNN		
LVEF		
35–50%	1·9 (0·87–4·49)	0·10
<35%	3·9 (1·69–9·25)	0·001
SDNN (ms)		
70–105	1·9 (0·86–4·04)	0·11
<70	3·2 (1·42–7·36)	0·005
⩾10 VPC/h	1·8 (0·97–3·50)	0·06

Table 4: **Multivariate Cox proportional-regression models**

- Monitoring Short (2-30 min) or longer (24 hour) periods
- Decreased HRV associated with increased arrhythmia and mortality
- Use of HRV to predict SCD risk in patients with CAD is limited
  - Effect of ischemia and PCI on HRV
  - Effect of age, gender, medications (BB or ACEi)
  - Atrial fibrillation

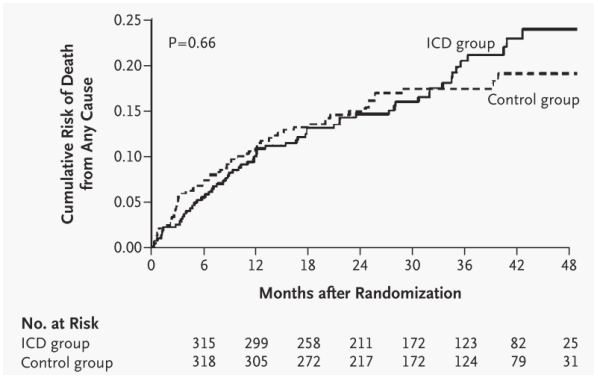
Lancet 1998;351:478

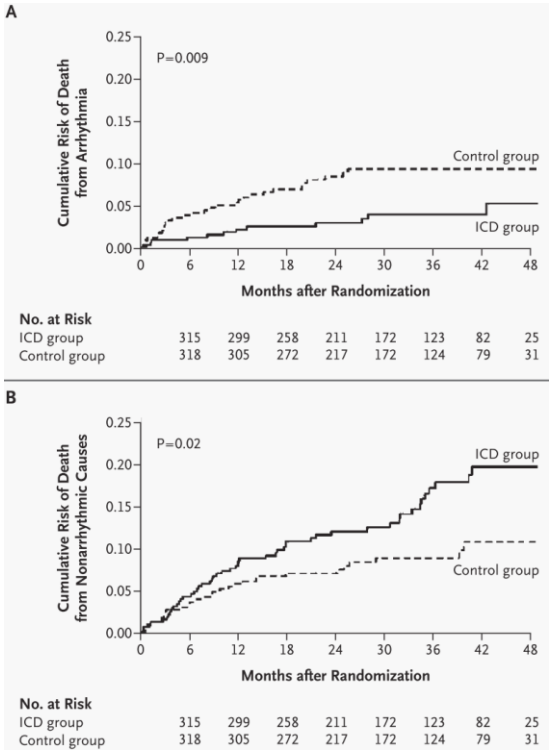
HRV

DYNAMIT trial

PATIENT POPULATION

Patients aged 18 to 80 years were eligible if they had recently had a myocardial infarction (6 to 40 days previously) and if they had a left ventricular ejection fraction of 0.35 or less, as assessed by angiography, radionuclide scanning, or echocardiography. Patients also had to have a standard deviation of normal-to-normal RR intervals of 70 msec or less or a mean RR interval of 750 msec or less (heart rate, 80 beats per minute or greater) over a 24-hour period,[8-12] as assessed by 24-hour Holter monitoring performed at least three days after the infarction.

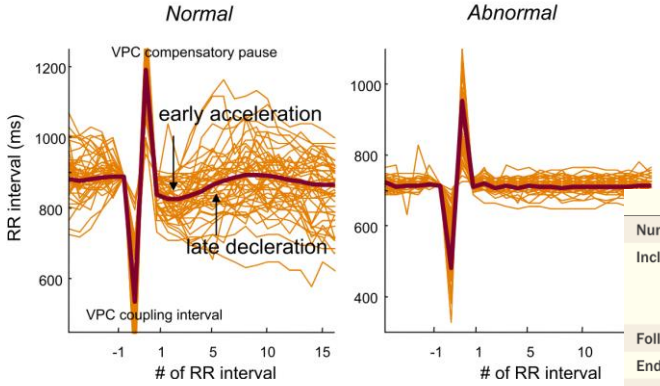


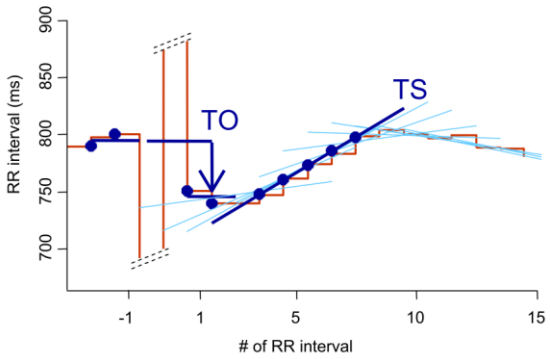


- Impaired autonomic function are associated with increased mortality
- ICD implantation failed to demonstrate the benefit in patients with LVEF + HRV patients
- Reduced death from arrhythmia which was offset by non-arrhythmic death

N Engl J Med 2004;351:2481

HR turbulence





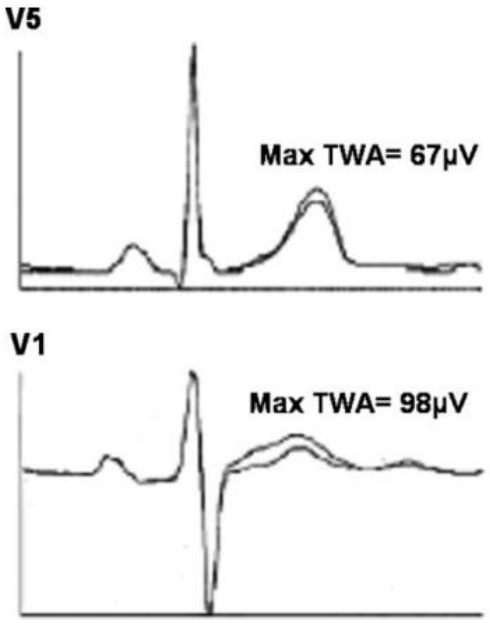
	MPIP	EMIAT	ATRAMI	CAST	ISAR-HRT	FINGER	REFINE
Number of patients	577	614	1,212	744	1,455	2,130	322
Inclusion criteria*	MI ≤4 weeks Age ≤70 yrs	MI ≤4 weeks Age ≤75 yrs LVEF ≤40%	MI ≤4 weeks Age ≤80 yrs	MI ≥6 VPC/h	MI ≤4 weeks Age ≤75 yrs	MI ≤4 weeks Age ≤75 yrs	MI LVEF <50%
Follow-up (months)	22	21	20	55	22	33	47
End point	Mortality	Mortality	Cardiac mortality†	Mortality	Mortality	Sudden death	Cardiac death
End points reached (%)	13	14	4	29‡	5	2	9
Treatment of acute MI	None	60% lysis	63% lysis	28% lysis	90% PCI 6% lysis	70% PCI 14% lysis	45% PCI 21% lysis
Mean LVEF (%)	45	30	49	37	56	Not specified	47
Beta-blockers (%)	55	32	20§	30	93	94	92
Univariate analysis							
HRT category 2	5.0 (2.8–8.8)	4.4 (2.6–7.5)	6.9 (3.1–15.5)	Not specified	11.4 (5.7–22.8)	4.6 (2.6–8.1)‖	2.9 (1.1–7.5)¶
LVEF ≤30%	4.0 (2.5–6.4)	2.2 (1.4–3.5)	4.7 (2.6–8.3)	Not specified	7.1 (4.2–12.1)	4.5 (2.5–8.0)#	3.3 (1.4–7.6)
Multivariate analysis							
HRT category 2	3.2 (1.7–6.0)	3.2 (1.8–5.6)	4.1 (1.7–9.8)	20.4 (10.2–30.6)**	5.9 (2.9–12.2)	2.9 (1.6–5.5)	Not specified
LVEF ≤30%	2.9 (1.8–4.9)	1.7 (1.1–2.7)	3.5 (1.8–7.1)	Not specified	4.5 (2.6–7.8)	Not specified	Not specified

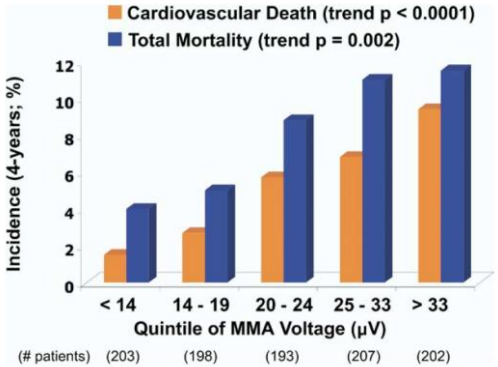
- Short term fluctuation in sinus CL after VPCs
- Powerful predictor of SCD in patients with CAD
- Compensatory Mx to PVC induced CO↓ + low SBP
  → baroreceptor activation
- Affected by age, medication, LV function, revascularization
- Not tested in the prospective data

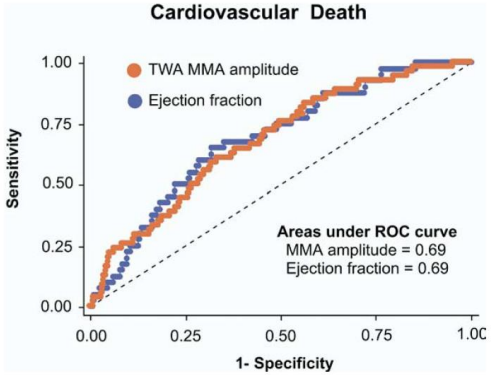
J Am Coll Cardiol 2008;52:1353

T wave alternans

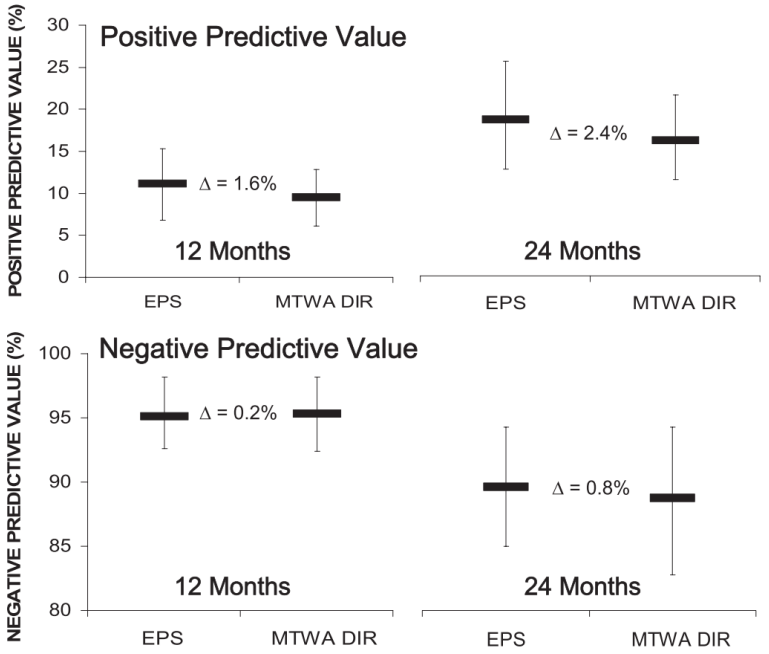
REVINE and FINCAVAS







ABCD study



- Dispersion of repolarization
- Increased TWA associated with SCD
- MTWA achieved 1-year PPV 9% and NPV 95%, comparable to EPS
- Useful for identifying low-risk patients.

Clin Cardiol 2011;34:466
J Am Coll Cardiol 2009;53:1130
J Am Coll Cardiol 2009;53:471

서울아산병원 Asan Medical Center

울산대학교

Current status

ESC European Society of Cardiology
Europace (2020) **22**, 1147–1148
doi:10.1093/europace/euaa065

EHRA POSITION PAPER

European Heart Rhythm Association (EHRA)/Heart Rhythm Society (HRS)/Asia Pacific Heart Rhythm Society (APHRS)/Latin American Heart Rhythm Society (LAHRS) expert consensus on risk assessment in cardiac arrhythmias: use the right tool for the right outcome, in the right population

Jens Cosedis Nielsen (EHRA Chair)[1]*, Yenn-Jiang Lin (APHRS Co-Chair)[2], Marcio Jansen de Oliveira Figueiredo (LAHRS Co-Chair)[3], Alireza Sepehri Shamloo[4], Alberto Alfie[5], Serge Boveda[6], Nikolaos Dagres[4], Dario Di Toro[7], Lee L. Eckhardt[8], Kenneth Ellenbogen[9], Carina Hardy[10], Takanori Ikeda[11], Aparna Jaswal[12], Elizabeth Kaufman[13], Andrew Krahn[14], Kengo Kusano[15], Valentina Kutyifa[16,17], Han S. Lim[18,19], Gregory Y.H. Lip[20,21], Santiago Nava-Townsend[22], Hui-Nam Pak[23], Gerardo Rodríguez Diez[24], William Sauer[25], Anil Saxena[26], Jesper Hastrup Svendsen[27,28], Diego Vanegas[29], Marmar Vaseghi[30], Arthur Wilde[31], and T. Jared Bunch (HRS Co-Chair)[32], ESC Scientific Document Group: Alfred E. Buxton[33], Gonzalo Calvimontes[34], Tze-Fan Chao[2], Lars Eckardt[35], Heidi Estner[36], Anne M. Gillis[37], Rodrigo Isa[38], Josef Kautzner[39], Philippe Maury[40], Joshua D. Moss[41], Gi-Byung Nam[42], Brian Olshansky[43], Luis Fernando Pava Molano[44], Mauricio Pimentel[45], Mukund Prabhu[46], Wendy S. Tzou[47], Philipp Sommer[48], Janice Swampillai[49], Alejandro Vidal[50], Thomas Deneke (Reviewer Coordinator)[51], Gerhard Hindricks[4], and Christophe Leclercq (ESC-CPG representative)[52]

서울아산병원 Asan Medical Center

울산대학교

Electrocardiographic methods including monitoring	Class	References
Twelve-lead electrocardiogram (ECG) should be obtained in all patients undergoing evaluation for known or suspected heart disease.		17
The 12-lead ECG provides diagnostic and prognostic information in patients with inherited high-risk syndromes including long QT syndrome (LQTS), short QT syndrome, Brugada Syndrome, and arrhythmogenic cardiomyopathy (ACM) and should be obtained.		17
Exercise ECG provides diagnostic and prognostic information for patients with LQTS ACM, hypertrophic cardiomyopathy (HCM), catecholaminergic polymorphic ventricular tachycardia, and documented or suspected arrhythmias related to exertion, and should be obtained.		17
Ambulatory ECG evidence of non-sustained ventricular tachycardia provides prognostic information in ischaemic cardiomyopathy, ACM, and HCM and should be obtained.		17
The signal-averaged ECG and QRS fragmentation may aid in the diagnosis of ACM.		18
The signal-averaged ECG and QRS fragmentation may be useful in risk stratification of Brugada syndrome.		18
Heart rate variability, heart rate turbulence, signal-averaged ECG, and T wave alternans analysis, when used in combination with additional clinical, electrocardiographic, and structural measures, may be useful for identifying high- and low-risk groups among patients with acquired structural heart disease.		19

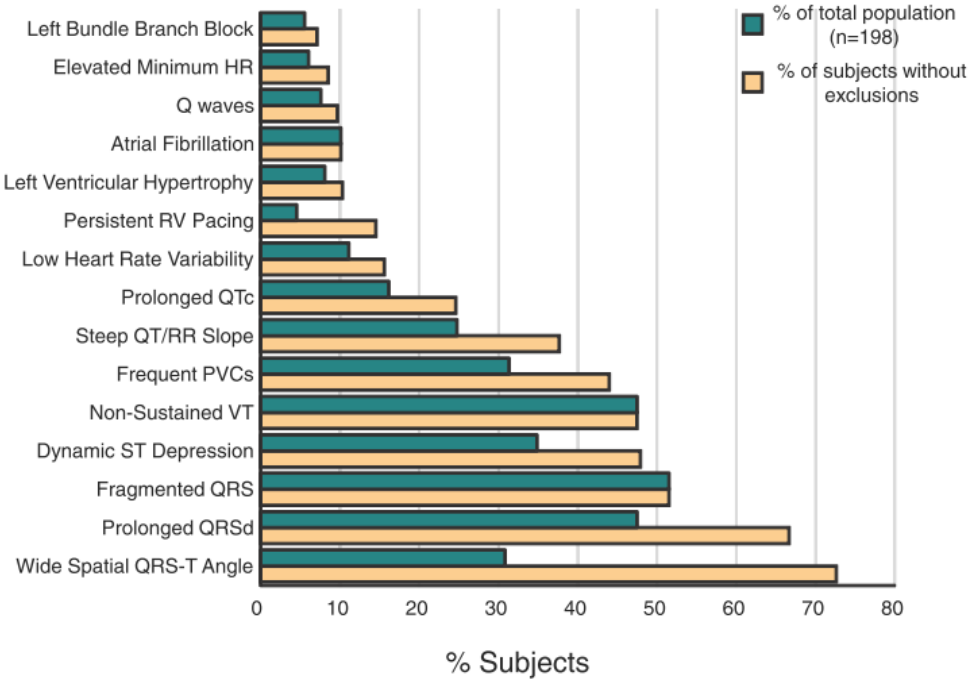
서울아산병원 Asan Medical Center

울산대학교

Europace 2020;22:1147

Primary prevention of VT/VF in patients with ICM and LVEF > 35%	Class	References
ICM substrate and ischaemic triggers for VT/VF must be evaluated when appropriate (coronary angiogram, functional ischaemic evaluation by nuclear scan, stress-echocardiography or MRI).		54,70,71
EPS and non-sustained VT evaluation could be considered to improve VT/VF risk stratification in patients with relatively preserved LVEF, particularly in the convalescent phase (first 2 months) after an acute coronary syndrome.		311,373,374
Heart rate variability (HRV), LVP, baroreflex sensitivity, QT-interval dispersion, T-wave alternans and heart rate turbulence have not been evaluated adequately in this population for generalized use.		73,371,372

Limitations of ECG parameters

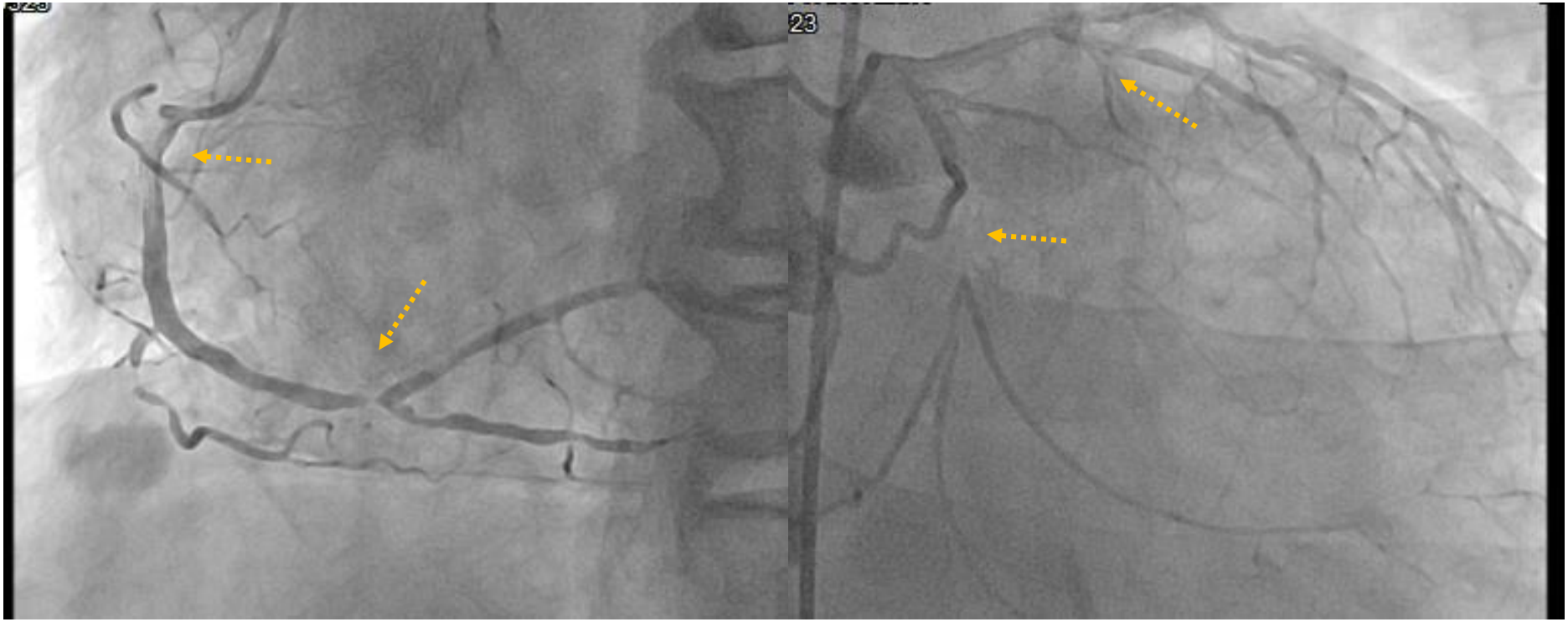


- ECG parameters are ubiquitous in patients with ischemic cardiomyopathy
- Generally good NPV, but poor PPV
- ECG is big-picture of myocardial depolarization and repolarization
- Lack of prospective studies with intervention

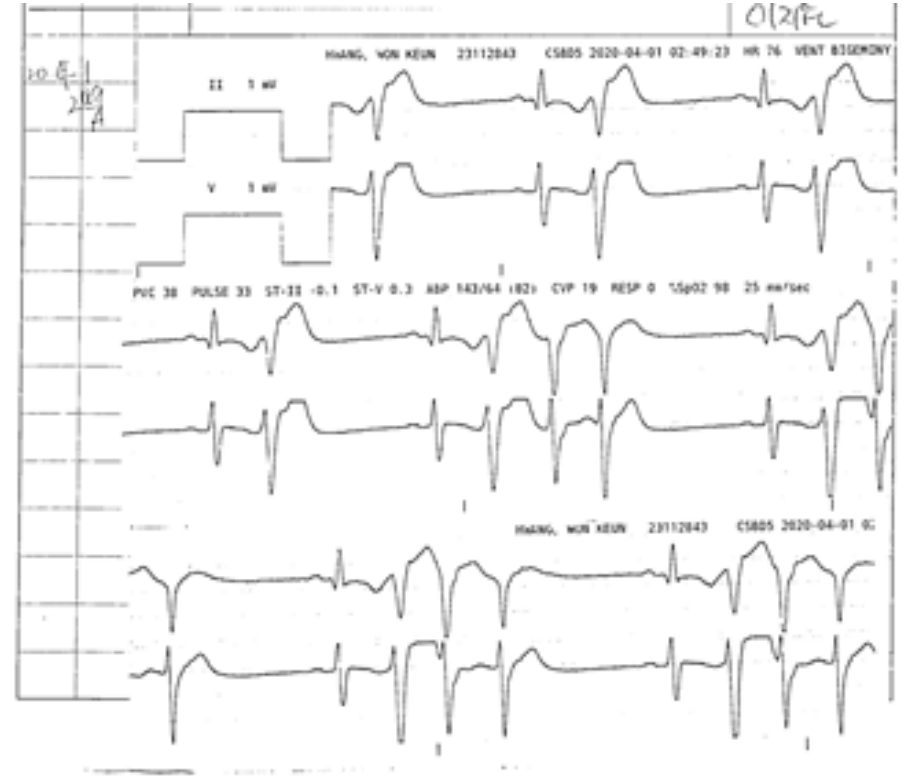
ECG-Based Test	Advantages	Disadvantages/Limitations	Practical Value for Risk Stratification
12-lead ECG	Cheap, quick and easy to perform; can be obtained serially at each follow-up visit to reassess risk; large databases can be generated and analyzed retrospectively/ prospectively	Many abnormal parameters are markers of increased mortality, rather than specifically SCD; low positive predictive and negative predictive accuracies; subject to interobserver variability (unless automated software is used); considerable overlap in some parameters between healthy subjects and patients	Remains a standard investigation in patients with CAD; low positive and negative predictive accuracies for SCD limit its practical use in risk stratification and selection of ICD candidates
Signal-averaged ECG	Easy and quick to perform; high negative predictive accuracy; can be used in patients with AF	Low positive predictive accuracy; numerous negative studies, especially in current era of interventional cardiology; better at predicting risk of VT than VF; normal standards for patients with bundle branch block or paced rhythm have not been established	Improved risk stratification when used in combination with other tests; probably more useful in identifying low-risk patients; not useful alone for risk stratification
Standard 24-hr Holter	Provides information on other arrhythmias in patients with CAD (eg, AF, heart block); standard test, easy to perform; can be used in patients in AF or paced rhythms	Low sensitivity and specificity	Most promising use is in combination with other parameters (eg, HRV and HRT) obtained from Holter recordings; not useful alone for risk stratification
Heart rate variability	Can be automatically recorded with standard Holter (using additional software); short (2–30 min) and longer (24 h) measurements are possible	Cannot be reliably assessed in patients with AF or frequent PVCs Influenced by a number of factors (eg, age, medication); may be affected by functional state of sinus node; short-term measurements in risk prediction have not been well tested; no consensus on which parameters of HRV or method of assessment is best	Current practical use for risk stratification is limited as a consensus opinion on which parameters of HRV to record and which method of assessing HRV is required
Heart rate turbulence	Value in risk prediction post-AMI supported by several recent large-scale prospective studies; provides prognostic information in patients with normal and impaired LVEF	Optimal time post-AMI to perform the test has not been established; can only be performed in patients in SR with a significant number of PVCs; use in patients with CAD and no history of AMI not well established	A promising test for risk prediction that can be used with other Holter-based measurements; limited practical use at present in the absence of clear guidelines for risk stratification
T-wave alternans	Easy to perform; can use existing equipment or modification of equipment; high negative predictive accuracy	Can only be used in patients in SR; "clean" ECG trace required (difficult to obtain during exercise); indeterminate result if target heart rate not achieved during exercise; low positive predictive accuracy	Useful in risk stratifying patients with impaired and preserved LVEF; useful role in determining which patients are unlikely to benefit from ICD insertion; improved risk stratification when used in combination with other tests; clear guidelines awaited for practical use for risk stratification

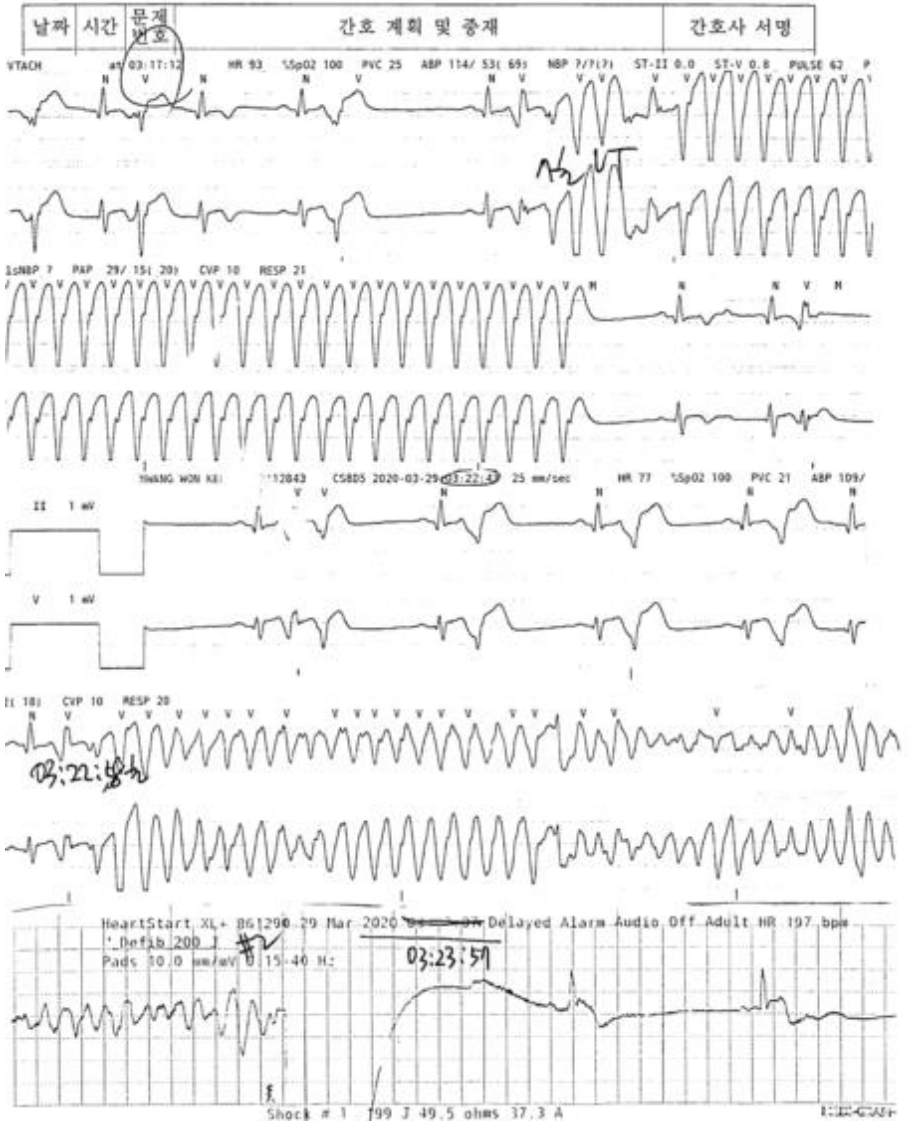
Abbreviations: AF, atrial fibrillation; AMI, acute myocardial infarction; CAD, coronary artery disease; ECG, electrocardiogram; HRT, heart rate turbulence; HRV, heart rate variability; ICD, implantable cardioverter defibrillator; LVEF, left ventricular ejection fraction; PVC, premature ventricular complex; SCD, sudden cardiac death; SR, sinus rhythm; VF, ventricular fibrillation; VT, ventricular tachycardia.

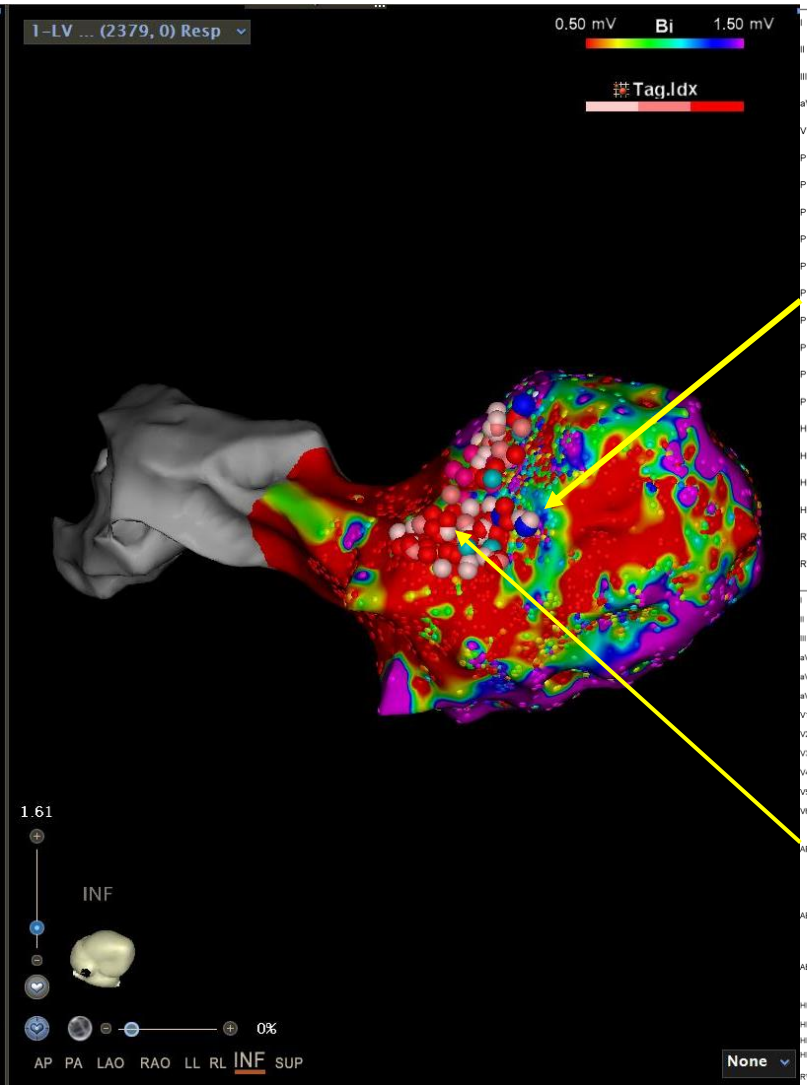
Coronary angiography

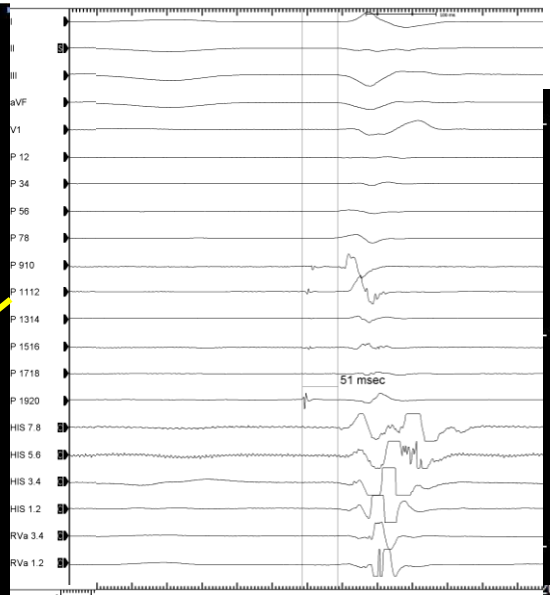


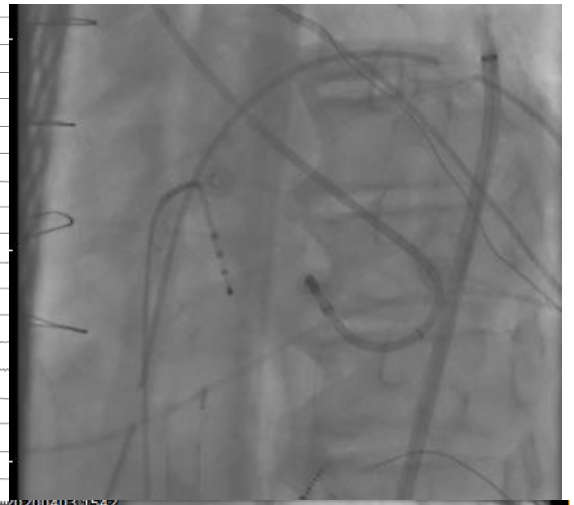
- NSTEMI with congestive heart failure
- Proceed urgent CABG

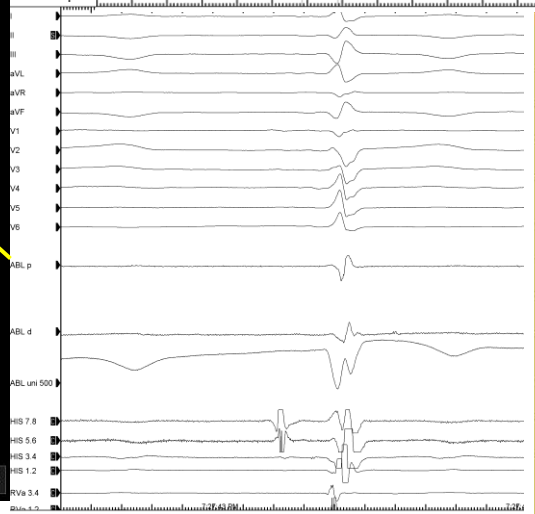

HWANG, WON KEUN 23112843 CS8D5 2020-04-01 02:49:23 HR 76 VENT BIGEMINY
II 1 mV
V 1 mV
PVC 38 PULSE 33 ST-II -0.1 ST-V 0.3 ABP 143/64 (82) CVP 19 RESP 0 %SpO2 98 25 mm/sec
HWANG, WON KEUN 23112843 CS8D5 2020-04-01

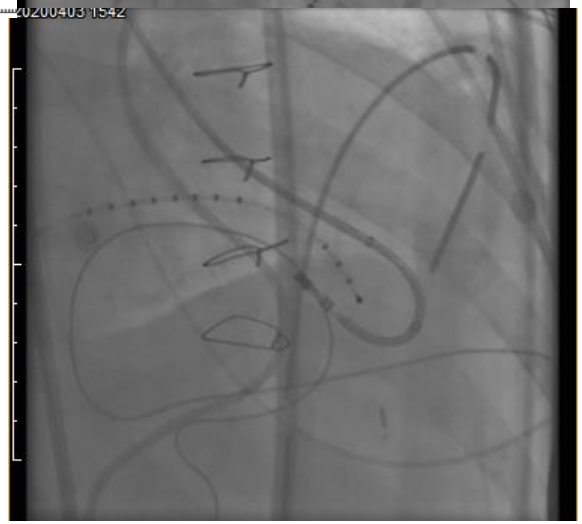

날짜
시간
문제 번호
간호 계획 및 중재
간호사 서명
VTACH
HR 93 %SpO2 100 PVC 25 ABP 114/ 53(69) NBP ?/?(?) ST-II 0.0 ST-V 0.8 PULSE 62
HWANG WON KEU 23112843 CS8D5 2020-03-29 03:22:4 25 mm/sec HR 77 %SpO2 100 PVC 21 ABP 109/
II 1 mV
V 1 mV
CVP 10 RESP 20
03:22:58
HeartStart XL+ 861290 29 Mar 2020 Delayed Alarm Audio Off Adult HR 197 bpm
Defib 200 J
Pads 10.0 mm/mV 0 15-40 Hz
03:23:5
Shock # 1 199 J 49.5 ohms 37.3 A


1-LV ... (2379, 0) Resp
0.50 mV
Bi
1.50 mV
Tag.Idx
1.61
INF
0%
AP PA LAO RAO LL RL INF SUP
None

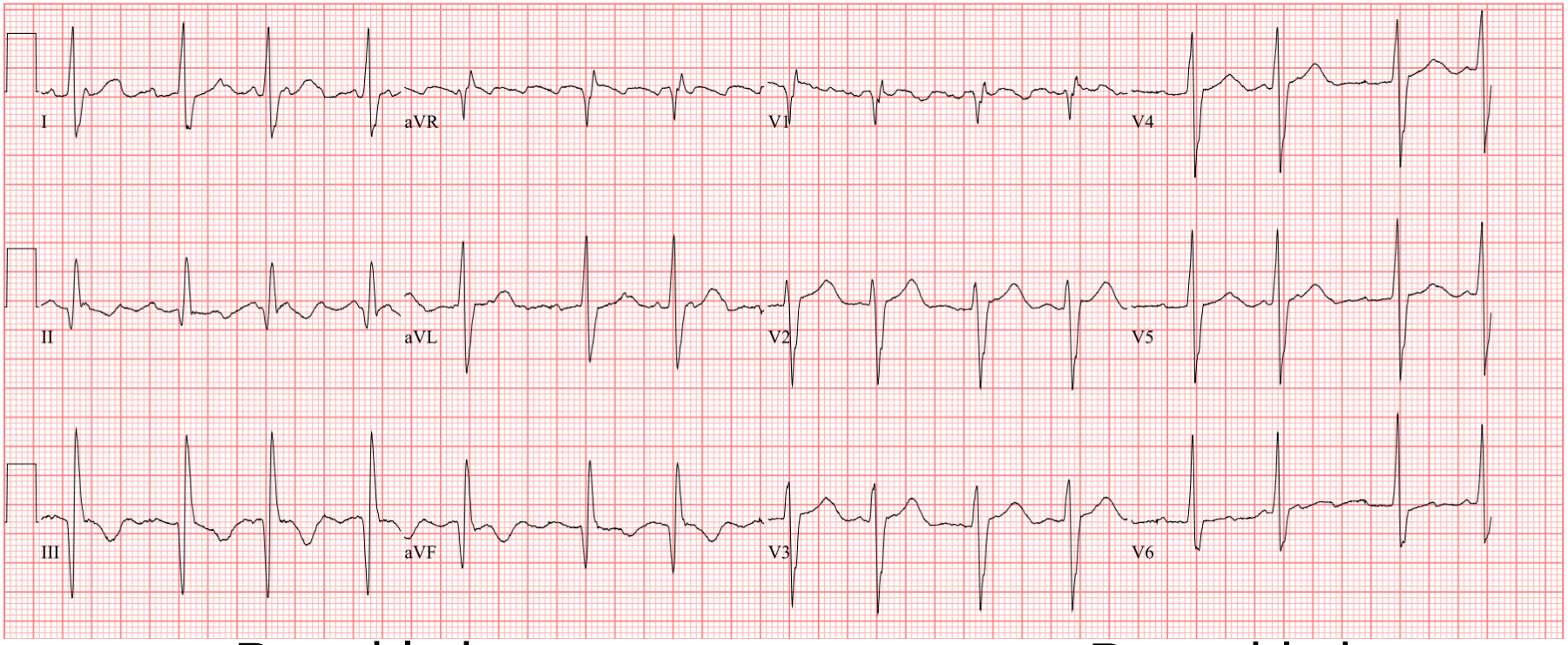

I
II
III
aVF
V1
P 12
P 34
P 56
P 78
P 910
P 1112
P 1314
P 1516
P 1718
P 1920
HIS 7.8
HIS 5.6
HIS 3.4
HIS 1.2
RVa 3.4
RVa 1.2
51 msec



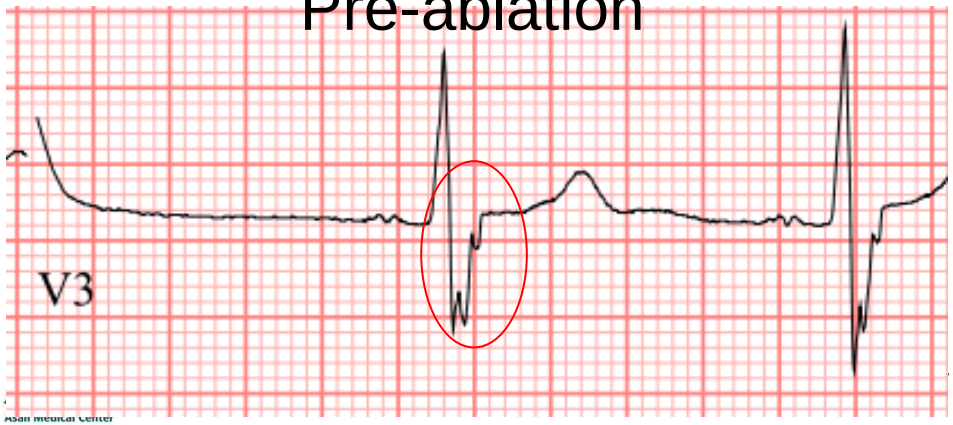

I
II
III
aVL
aVR
aVF
V1
V2
V3
V4
V5
V6
ABL p
ABL d
ABL uni 500
HIS 7.8
HIS 5.6
HIS 3.4
HIS 1.2
RVa 3.4



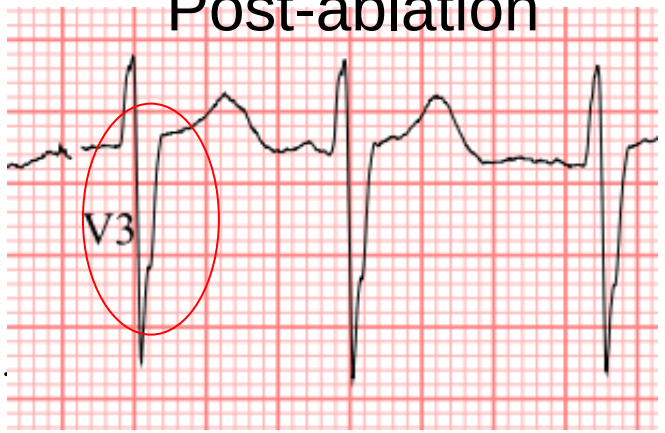
Post-procedure ECG



Pre-ablation



Post-ablation



울산대학교

Summary

- CAD with EF>35% are large group of patients unprotected by current guideline
- Several parameters provide prognostic information, but their sole use in predicting SCD is limited
- ECGs are still useful for clinicians
  - Markers of significant LV dysfunction
  - Perform additional investigations to refine the risk of SCD
- Future studies for the better refinement of ECG predictors are required