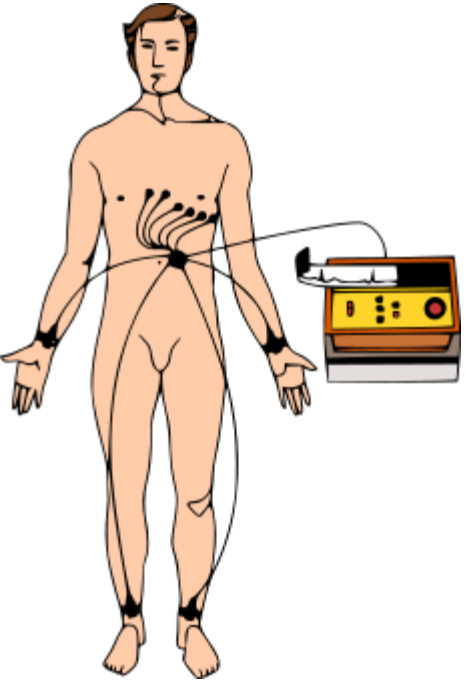
Example 4: Automated interpretation of electrocardiograms

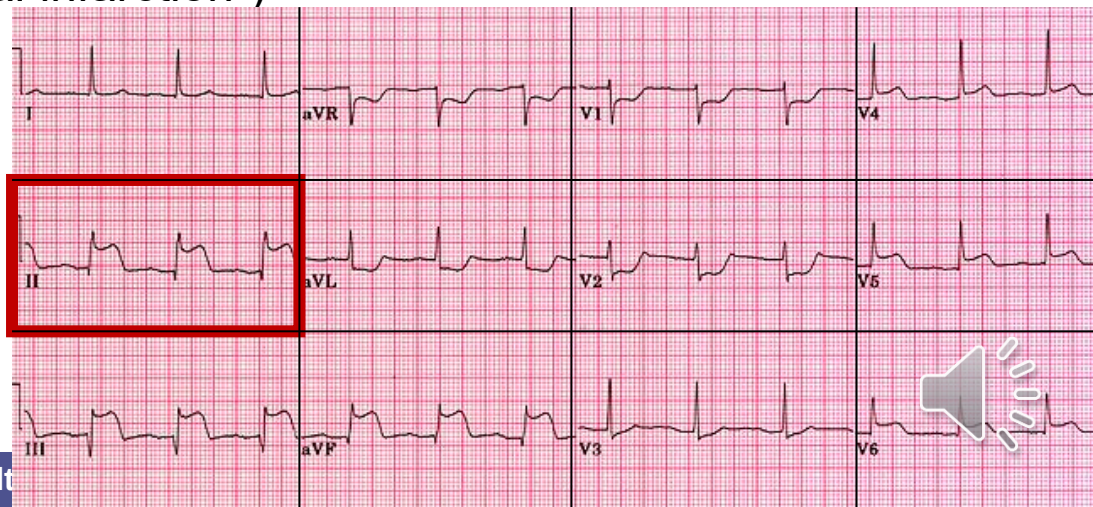
Université de Lille

Electrocardiography for dummies

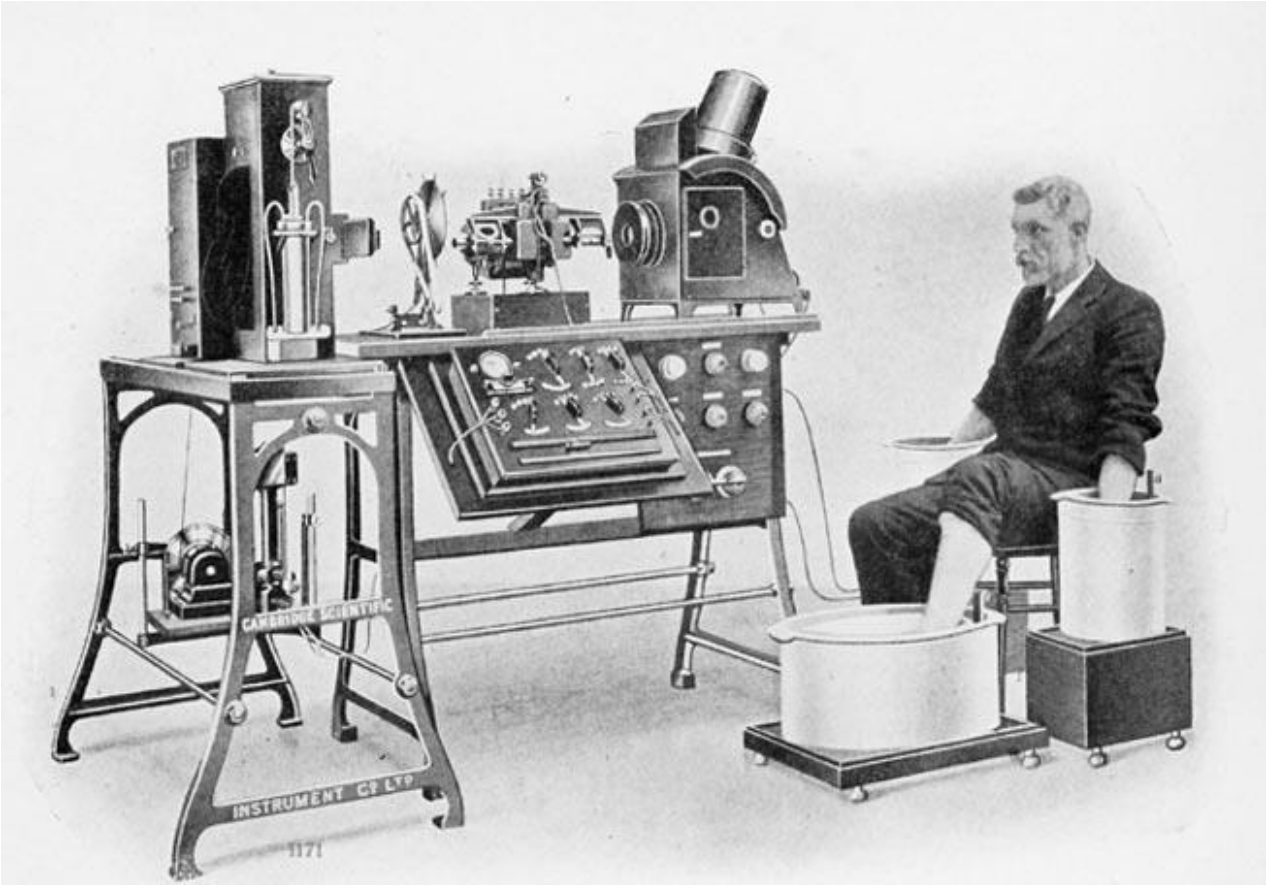
Introduction to electrocardiography



- Definition
  - Recording of the electrical activity of the heart
  - Non-invasive exam: usually 10 probes pasted on the skin
  - Routinely used, not expensive
- Outcome:
  - 12 charts of the electric signal of the heart (12 points of view) during a few seconds
  - Complex analysis: cardiologists, few GPs only
  - Immediate diagnosis of some heart diseases (e.g. atrial fibrillation), sometimes with localization (e.g. “acute lateral myocardial infarction”)



Willem Einthoven, Leiden, string galvanometer, 1901. Nobel, 1924.



PHOTOGRAPH OF A COMPLETE ELECTROCARDIOGRAPH, SHOWING THE MANNER IN WHICH THE ELECTRODES ARE ATTACHED TO THE PATIENT, IN THIS CASE THE HANDS AND ONE FOOT BEING IMMERSED IN JARS OF SALT SOLUTION

An early commercial ECG device (1911)

Electrocardiographic data

```
<?xml version='1.0' encodin
<contenu_examen>
  <echantillonnage>300 par
  <sensibilite>5 microvolts
  <enregistrement>
    <numero>1</numero>
    <date>10/01/2012 13:38:
    <vitesse>25 mm par secc
    <frequence_cardiaque>70
    <filtre60hz>NAO</filtre
    <derivations>
      <canal id="DI"><valeu
      <canal id="DII"><vale
      <canal id="DIII"><val
      <canal id="AVR"><vale
      <canal id="AVL"><vale
      <canal id="AVF"><vale
      <canal id="V1"><valeu
      <canal id="V2"><valeu
      <canal id="V3"><valeu
      <canal id="V4"><valeu
      <canal id="V5"><valeu
      <canal id="V6"><valeu
    </derivations>
  </enregistrement>
</contenu_examen>
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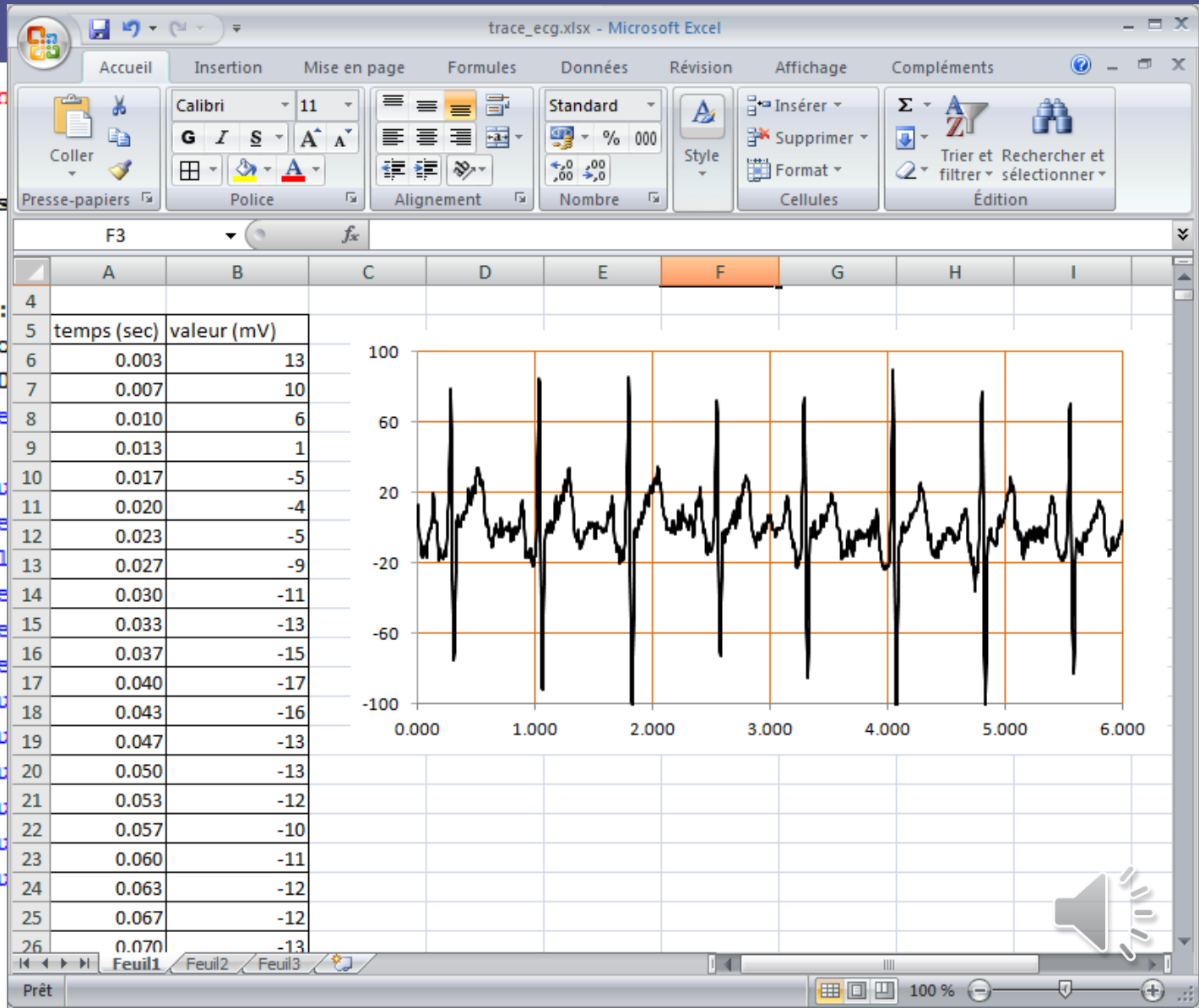
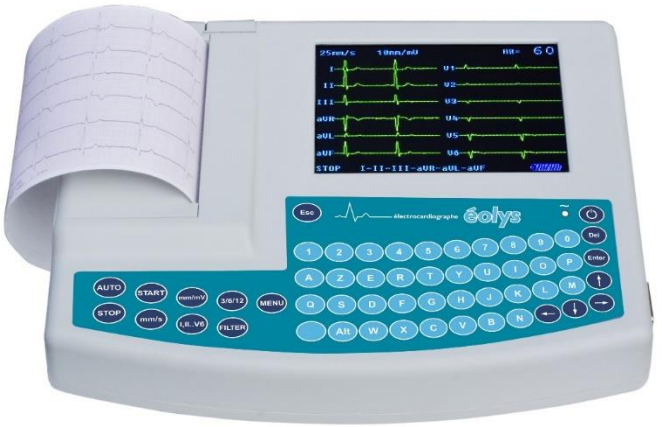
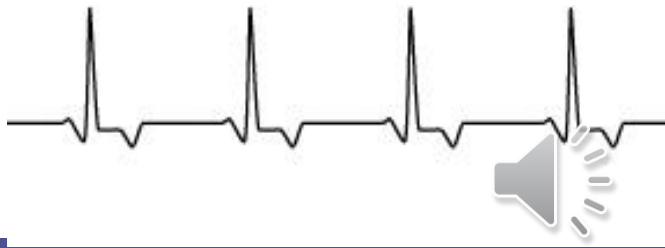


Cardiovascular diseases and ECG

- Cardiovascular disease
  - 17.5 million death/year (World Health Organization ; 42% coronary heart disease, 38% stroke)
  - third cause of death before 65 years
- In France, in primary care
  - Cardiovascular risk factors = 13% of visits
  - Cardiovascular diseases = 7.7% of emergency visits
- Electrocardiography (ECG): the most widely used procedure for diagnosis, notably myocardial infarction.





ECG computerized interpretation (ECG-CI, first attempts in 1950s)

Acquisition

- Electric signal: voltages
- 300 pts/sec, during 12 sec, in 12 leads

Signal analysis

- Waves identification (P, QRS, etc.)
- Measurement of voltages and spaces x12 leads, x~15 heart cycles

Good results since the 1980s

Aggregation

- Heart rate, means, variability, etc.

Interpretation

- Expert rules or machine learning => diagnosis

Still bad results!

Evaluation of an ECG computerized interpreter

group	varname	kappa
Global	normal variant	0.004
	error nonfatal	0.098
	permanent pacemaker	0.195
A Morph	left ventricular hypertrophy	0.382
	right ventricular hypertrophy	0.111
A Isch	myocardial infarction	0.267
B Cond	deg1 atrio ventricular block	0.499
	left bundle branch block	0.551
	right bundle branch block	0.706
	wolff parkinson white	0.499
B Repol	repolarization abnormality	0.04
B Rhythm	sinus rhythm	0.428
	sinus bradycardia	0.441
	sinus or supravent tachycardia	0.526
	atrial fibrillation flutter	0.66
	multifocal or ectopic atrial rhythm	0.31
	prem atrial contraction or supraventricular extrasyst	0.27
	junctional rythm normal or acc	-0.002
	ventricular extrasyst	0.401
C	tachycardia	0.56
	bradycardia	0.441
	pr short	0.081
	axis deviation	0.547
	qt long	-0.002

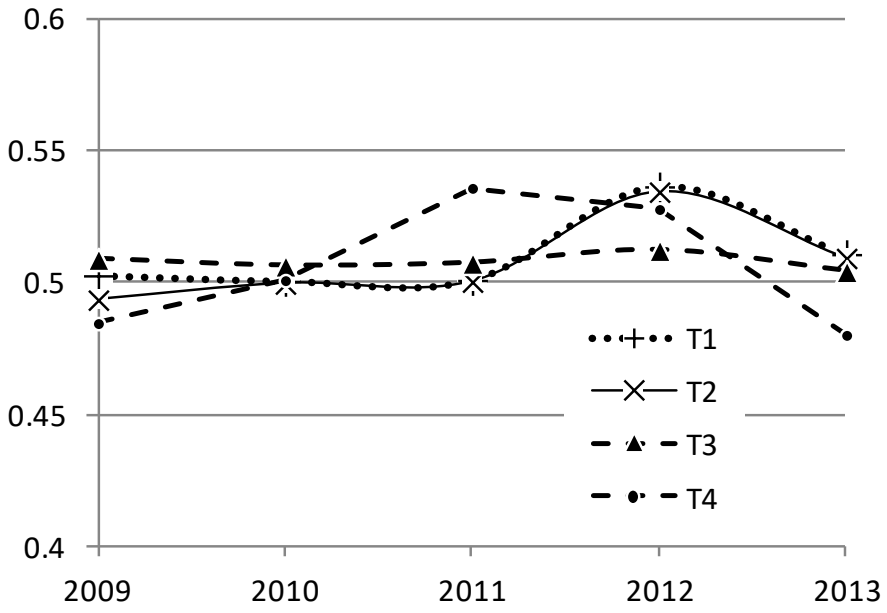
Validation study of a commercial ECG-CI

Agreement between the software and the gold standard
(3 cardiologists), study of 900 records

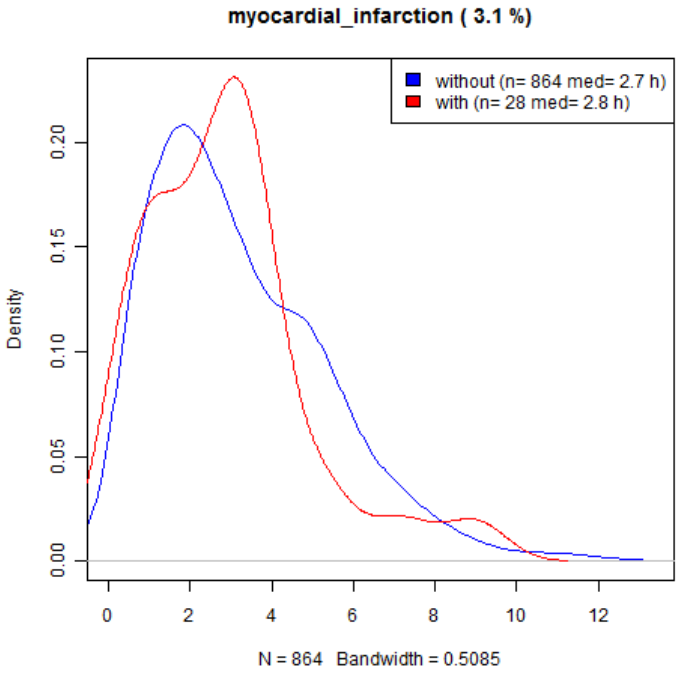
Kappa coefficient:
-Random answer: k=0
-Full agreement: k=1

Is the software reliable?
NO!

May the ECG-CI be used to identify abnormal ECGs (without precise diagnosis)?



Estimated prevalence rate of normal (or normal variant) ECGs, using 4 different methods.



Time required to get the ECG interpreted

Chazard E, Marcolino MS, Dumesnil C, Caron A, Palhares DM, Ficheur G, Marino BC, Alkmim MB, Beuscart R, Ribeiro AL. One Million Electrocardiograms of Primary Care Patients: A Descriptive Analysis. Stud Health Technol Inform. 2015;216:69-73.

Performance of normal ECG detection

Evaluation of the identification of "normal ECGs", using 5 different methods

threshold	0.5
algo	1
Sensitivity	59.6%
Specificity	83.6%
Pos Pred Value	79.8%
Neg Pred Value	65.5%
Kappa	42.7%
Harm Mean	68.2%

threshold	1.5
algo	1
Sensitivity	65.6%
Specificity	75.4%
Pos Pred Value	74.4%
Neg Pred Value	66.8%
Kappa	40.8%
Harm Mean	69.7%

threshold	2.5
algo	1
Sensitivity	67.7%
Specificity	73.3%
Pos Pred Value	73.4%
Neg Pred Value	67.6%
Kappa	40.9%
Harm Mean	70.5%

threshold	0.5
algo	10
Sensitivity	57.0%
Specificity	84.1%
Pos Pred Value	79.6%
Neg Pred Value	64.2%
Kappa	40.6%
Harm Mean	66.4%

threshold	0.5
algo	11
Sensitivity	87.1%
Specificity	45.2%
Pos Pred Value	63.4%
Neg Pred Value	76.3%
Kappa	32.8%
Harm Mean	73.4%

Attempt to improve the detec tion of normal ECGs, using context variables

Decision tree with context variables:

root	346	0.801
Smoking	22	0.591
Arterial hypertension	10	0.400 *
No Arterial hypertension	12	0.750 *
No Smoking	324	0.815
Age < 16 or > 35	247	0.794
Male	83	0.747
Diuretics	16	0.500 *
No Diuretics	67	0.806 *
Female	164	0.817 *
Age 16-35	77	0.883 *

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What the literature says…

Bibliographic review

			Brunetti 2011	Chiu 2007	Giuliano 2012	Guglin 2006	Helppi 1973	Iacoviello 2012	Physio-Control 2009	Shah 2007	Widman 1996	Willems 1990	Willems 1991	Willems 1987	Wong 2002
General data	Symptoms	typical chest pain	1	0	0	0	0	0	0	0	0	0	0	0	0
		atypical chest pain	1	0	0	0	0	0	0	0	0	0	0	0	0
		breathlessness	1	0	0	0	0	0	0	0	0	0	0	0	0
		epigastric pain	1	0	0	0	0	0	0	0	0	0	0	0	0
		palpitations	1	0	0	0	0	0	0	0	0	0	0	0	0
		dizziness/syncope	1	0	0	0	0	0	0	0	0	0	0	0	0
		other symptoms	1	0	0	0	0	0	0	0	0	0	0	0	0
		no symptom	0	0	0	0	0	0	0	0	0	0	0	0	0
	Technical statements	Sinus rythm	0	1	0	0	0	0	1	1	0	0	0	0	0
		Normal ECG	0	0	1	0	0	1	1	0	0	1	0	0	0
		Normal variant / isolated or non specific abnorm	0	1	1	0	0	0	1	0	0	0	0	0	1
		Permanent pacemaker	0	0	0	1	0	0	0	1	0	0	0	0	0
		Various errors	0	0	0	0	0	0	0	0	0	0	0	0	0
Type A	Morphology	Left Atrial hypertrophy / enlargement / abnorma	0	0	1	1	0	0	0	0	0	0	0	0	2
		Right atrial hypertrophy / enlargement / abnorm	0	1	1	1	0	0	1	0	0	0	0	0	0
		Left ventricular hypertrophy	0	0	1	1	0	1	1	0	0	2	0	0	1
		Right ventricular hypertrophy	0	1	1	1	0	0	1	0	0	2	0	0	0
	Ischemia	Myocardial ischemia	0	0	2	1	0	0	0	0	0	0	0	0	0
	Acute infarction	Acute myocardial infarction	0	0	2	1	0	2	2	0	0	2	0	0	2
		Atrial infarction	0	0	1	0	0	0	0	0	0	0	0	0	0
		Anterior myocardial infarction (+/- possible)	0	0	0	0	0	1	1	0	0	1	0	0	1
		Lateral myocardial infarction	0	0	0	0	0	0	0	0	0	0	0	0	1
		Inferior myocardial infarction (+/- possible)	0	0	0	0	0	1	1	0	0	1	0	0	1
		Posterior Myocardial Infarction	0	0	0	0	0	0	0	0	0	0	0	0	1
		Septal myocardial infarction	0	0	0	0	0	0	0	0	0	0	0	0	1
		Combined myocardial infarction	0	0	2	0	0	2	2	0	0	2	0	0	2
	Other	Old myocardial infarction, fibrosis	0	0	1	1	0	0	0	0	0	0	0	0	0
Type B	Atrial rythm troubles	Premature atrial contractions / Supraventricular extrasy	0	0	1	1	0	0	0	0	0	0	0	0	0
		Sinus bradycardia	0	0	1	0	0	0	1	0	0	0	0	0	0
		Sinus tachycardia / Supraventricular tachycardia (+/- pr	0	0	1	0	0	0	2	0	0	0	0	0	1
		Atrial fibrillation / flutter (+/- probable)	0	0	1	2	0	0	1	1	0	0	0	0	1
		Sinus arrhythmia / multifocal atrial tachycardia / ectopic	0	1	1	0	0	0	2	2	0	0	0	0	0
		Paroxysmal supraventricular tachycardia	0	0	1	0	0	0	0	0	0	0	0	0	0
	Jct. ryth. trbl.	Junctional rhythm / Accelerated Junctional Rhythm / Ju	0	0	1	0	0	0	1	1	0	0	0	0	1
	Ventricular rythm	ventricular tachycardia	0	0	1	0	0	0	0	1	1	0	0	0	1
		Ventricular extrasystoles (premat. vent. contraction) / ve	0	0	1	1	0	0	0	0	0	0	0	0	0
	Supraventricular condution troubles	1M atrio-ventricular block	0	0	0.5	1	0	0	0	0	0.5	0	0	0	1
		2M Atrio-ventricular block	0	0	0.5	1	0	0	0	0	0.5	0	0	0	1
		3M Atrio-ventricular block / atrioventricular dissociated	0	0	0.5	0	0	0	1	1	0.5	0	0	0	0
		Wolff-Parkinson-White	0	0	1	0	0	0	1	1	0	0	0	0	0
		Idioventricular rhythm	0	0	1	0	0	0	0	0	0	0	0	0	0
	Ventricular conduction or repolarization	Intraventricular conduction defect	0	0	2	0	0	2	1	0	0	0	0	0	0
		Left bundle branch block	0	0	2	1	0	1	2	0	0	0	0	0	1
		Right bundle branch block	0	0	2	1	0	1	2	0	0	0	0	0	1
		Early or abnormal repolarization (incl. Brugada syndron	0	0	1	0	0	0	0	0	0	0	0	0	0
Type C	Misc	Heart rate (bpm)	0	0	0	0	0	1	0	0	0	0	0	0	0
	P	P amplitude	0	0	0	0	1	0	0	0	0	0	0	0	0
		P duration	0	0	0	0	1	0	1	0	0	0	0	1	0
		P axis	0	0	0	0	1	0	0	0	0	0	0	0	0
	PR	PR interval	0	0	1	0	0	1	0	0	0	0	0	1	0
	QRS	QRS amplitude	0	0	0	0	1	0	0	0	0	0	0	0	0
		QRS duration	0	0	0	0	1	1	1	0	0	0	0	1	0
		QRS axis or axis deviation	0	0	0	0	1	0	1	0	0	0	0	0	1
		Q duration	0	0	0	0	1	0	0	0	0	0	0	0	0
		R amplitude	0	0	0	0	1	0	0	0	0	0	0	0	0
		R duration	0	0	0	0	1	0	0	0	0	0	0	0	0
	QT	QT interval	0	1	0	0	1	1	1	0	0	0	0	1	1
		QT Dispersion	0	0	0	0	0	1	0	0	0	0	0	0	0
	ST, T	ST Duration	0	0	0	0	0	1	0	0	0	0	0	0	0
		ST elevation	0	0	0	0	1	0	1	0	0	0	0	0	0
		T amplitude	0	0	0	0	1	0	0	0	0	0	0	0	0
		T axis	0	0	0	0	1	1	0	0	0	0	0	0	0

Rows: messages of the ECG-CI (e.g. "myocardial infarction")

Columns: papers published in international scientific journals, with an ECG-CI evaluation

0	absent concept
0.5	more fuzzy concept
1	exact match
2	more precise concept

The computer vs. gold standard agreement in the literature… Salerno 2003 (review 1966-2002)

Paper	Field	N	Se	Sp	Agree*	Kappa
Goodacre 2001	All, emergency room	50				
Massel 2000	ECG criteria for thrombolysis	75	61.5%	100%		68%
Sekiguchi 1999	Abnormal ECG detection	1,058	87.4%	83.5%		
De Bruyne 1997	MI, BBB, VH	381	74-93%	97-99.8%		
Brailer 1997	All, selected by investigator. Cardiologists with computer, vs. GS	80			61%	
Heden 1996	Anterior MI	1,664			77%	
Heden 1996	Lead reversal detection	10,906	57-83%	99.8%		
Wildman 1996	Dysrhythmias	56			82.1%	
Woolley 1992	All, family medicine clinic	301			88%	
Shirataka 1992	Computer-generated arrhythmias	110			0-100%	
Willems 1991	Normal, AMI, VH	1,220			69.7%	
Willems 1990	AMI, VH	500			76.6%	61%
Thomson 1989	All (but publish VH, Arr, MI, ST-T, axis, conduction blocks)	5,110	83-94%	84-94%		

*Is it the “observed concordance”, with better values than Kappa, but not acceptable in scientific publications.

This was before… or?

Les Echos ENTREPRENEURS

[redacted] va traquer

LesEchos.fr | Startup | Gérer | Grandir | Ma vie d'entre

La start-up française vient de lever 5,3 millions d'euros pour entrer dans sa phase commerciale Outre-Atlantique.

Il y a des causes plus évidentes que d'autres. Et pour [redacted], cofondateur et PDG de [redacted], se lever le matin ne doit pas vraiment être un casse-tête : *« Savoir qu'avec notre technologie, des cardiologues vont sauver des vies est une belle source de motivation. »* Son entreprise, fondée en 2014 à Paris, vient d'obtenir une homologation de la FDA pour **commercialiser son produit aux États-Unis**, qui se destine aux praticiens du cœur.

This was before… or?

Les Echos ENTREPRENEURS

va traquer

Ma vie d'entre

ver 5,3

ns sa phase

e doit pas

echnologie, des

e de motivation. »

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roduit aux États-

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L'USINE SANTÉ

ACCUEIL | COSMÉTIQUE | PHARMACIE / BIOTECHNOLOGIES | ENTRETIEN / HYGIÈNE

[Portraits] Les start-uppers de l'IA 14 / 15

Décrypteur d'électrocardiogrammes : , PDG de Technologies

LA RÉDACTION | PUBLIÉ LE 07/02/2018 À 13H10

29 ans est PDG Technologies, Paris

This was before… or?

Les Echos
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Décrypteur d'

Technologies

LA RÉDACTION | PUBLIÉ LE 07/02

29 ans est PDG

ACCOMPAGNEMENT & FINANCEMENT

West Web Valley
accélérateur de startups

Vous êtes ici : Accueil > L'IA au service de votre coeur – Yann Fleureau – Cardiologs – West Web Festival 2017

L'IA AU SERVICE DE VOTRE COEUR – – WEST WEB FESTIVAL 2017

Venez découvrir comment , cofondateur et CEO de est devenu le deuxième cerveau des cardiologues du monde entier. Une conférence qui s'est déroulée au West Web Festival 2017 au côté associé de la West Web Valley.

This was before… or?

Les Echos ENTREPRENEURS

[redacted] va traquer

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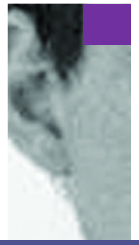
ACCUEIL | COSMÉTIQUE

Décrypteur d'é[redacted]

Technologies

LA RÉDACTION | PUBLIÉ LE 07/02/20

[redacted] 29 ans est PDG [redacted]



isai — LE FONDS D'INVESTISSEMENT DES ENTREPRENEURS INTERNET — A PROPOS — CAPITAL RISQUE

04.10.2017

[redacted] LÈVE 6.4M$ POUR MENER LA RÉVOLUTION DE L'INTELLIGENCE ARTIFICIELLE EN CARDIOLOGIE

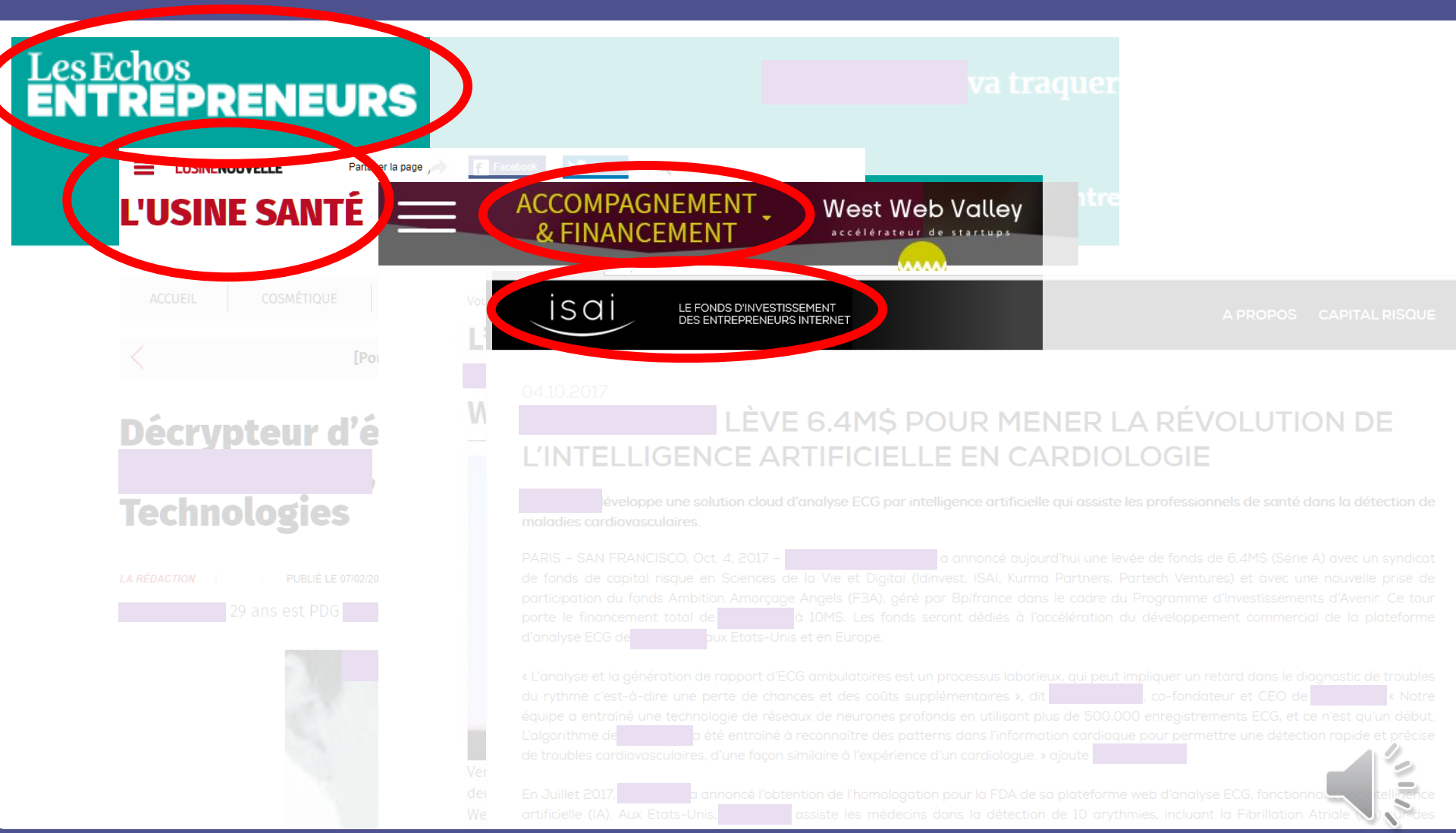
[redacted] développe une solution cloud d'analyse ECG par intelligence artificielle qui assiste les professionnels de santé dans la détection de maladies cardiovasculaires.

PARIS – SAN FRANCISCO, Oct. 4, 2017 – [redacted] a annoncé aujourd'hui une levée de fonds de 6.4M$ (Série A) avec un syndicat de fonds de capital risque en Sciences de la Vie et Digital (Idinvest, ISAI, Kurma Partners, Partech Ventures) et avec une nouvelle prise de participation du fonds Ambition Amorçage Angels (F3A), géré par Bpifrance dans le cadre du Programme d'Investissements d'Avenir. Ce tour porte le financement total de [redacted] à 10M$. Les fonds seront dédiés à l'accélération du développement commercial de la plateforme d'analyse ECG de [redacted] aux Etats-Unis et en Europe.

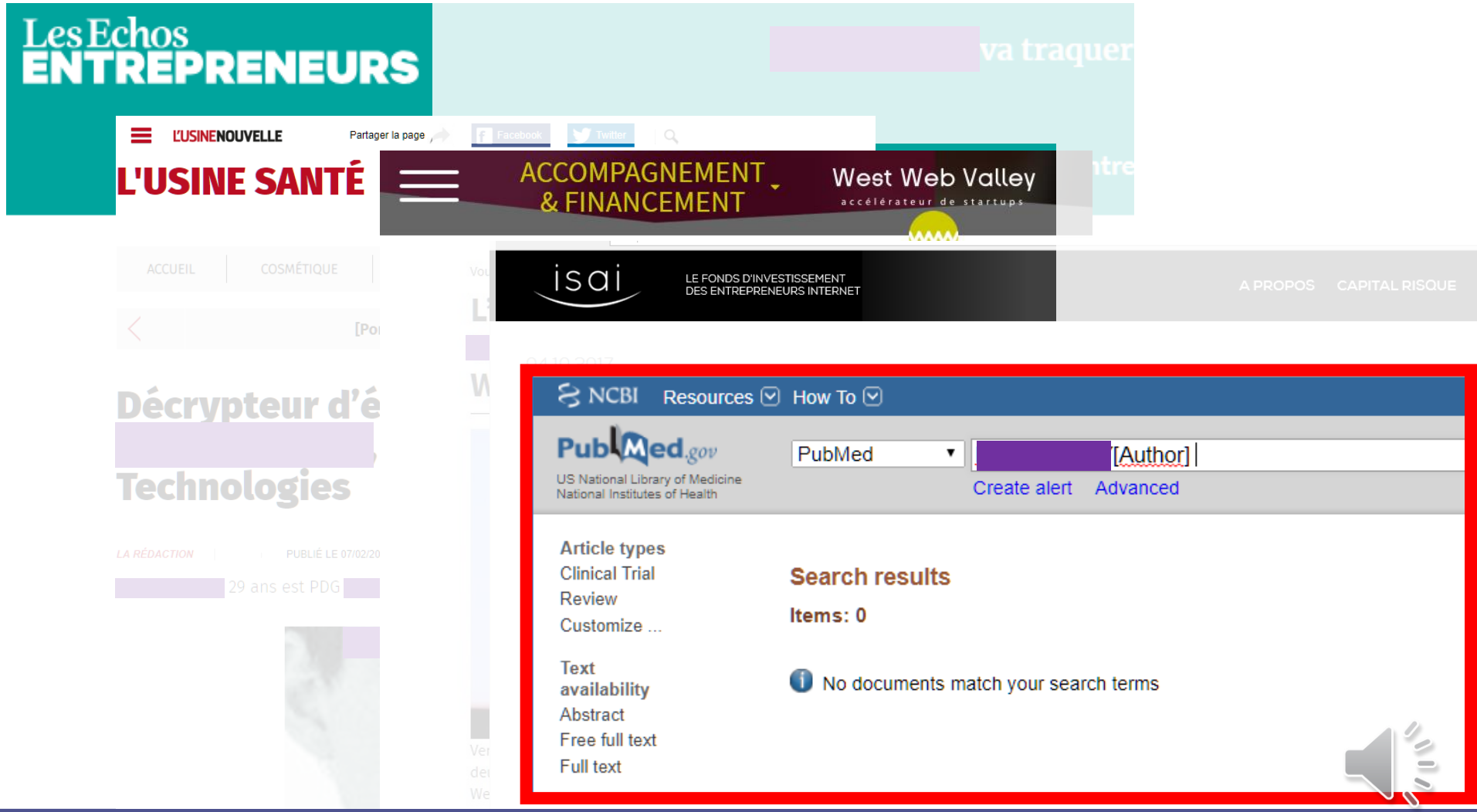
« L'analyse et la génération de rapport d'ECG ambulatoires est un processus laborieux, qui peut impliquer un retard dans le diagnostic de troubles du rythme c'est-à-dire une perte de chances et des coûts supplémentaires », dit [redacted], co-fondateur et CEO de [redacted] « Notre équipe a entraîné une technologie de réseaux de neurones profonds en utilisant plus de 500,000 enregistrements ECG, et ce n'est qu'un début. L'algorithme de [redacted] a été entraîné à reconnaître des patterns dans l'information cardiaque pour permettre une détection rapide et précise de troubles cardiovasculaires, d'une façon similaire à l'expérience d'un cardiologue. » ajoute [redacted]

En Juillet 2017, [redacted] a annoncé l'obtention de l'homologation pour la FDA de sa plateforme web d'analyse ECG, fonctionnant par intelligence artificielle (IA). Aux Etats-Unis, [redacted] assiste les médecins dans la détection de 10 arythmies, incluant la Fibrillation Atriale (FA) sur des

This was before… or?



This was before… or?



How can some manufacturers and researchers claim to obtain good results?

- Miscellaneous reasons:
  - Using computer-simulated ECGs
  - Present the “observed agreement coefficient” (not honest: always good for rare diseases)
  - The physicians first read the output, and say if they agree or not
  - The software is evaluated by its creators
  - Rarely peer-reviewed scientific papers, mostly technical reports that cannot be validated by researchers’ community

How can some manufacturers and researchers claim to have good results?

- Main reasons:
  - Compute only sensitivity and specificity
    - Not impacted by low prevalence rates
    - E.g. : Se=90%, Sp=90%, Prev=1%
      => positive predictive value=8.3%, Kappa=13.7%
  - Use non representative samples:
    - Study:
    - Real life:

Real-life use of automated ECG interpreters

Unfortunately, French GPs seem to trust such software!

- 225 French physicians questioned:

	GPs (n=154)	Cardiologists (n=71)
Self-perceived skills in ECG interpretation	36.7%	94.2%
ECG device in the office	49.4%	100%
Among them, ECG-CI	27.9%	50.7%

ECG-CI = ECG computerized interpreter

Delrot C, Bouzillé G, Calafiore M, Rochoy M, Legrand B, Ficheur G, Chazard E. Do Medical Practitioners Trust Automated Interpretation of Electrocardiograms? Stud Health Technol Inform. 2019 Aug 21;264:536-540. doi: 10.3233/SHTI190280.

PCPs having or not an ECG device (n=154)

more likely men, working alone, in rural areas

more likely working in emergency

further from cardiologists and ED

followed more postgraduate courses

	Ps with ECG (n=76)	Pthout CG (n=78)	p value
Men	56 (73.7%)	40 (51.3%)	0.005
Urban practice location	31 (40.8%)	49 (63.6%)	0.003
Group practice	35 (46.1%)	53 (68%)	0.028
Emergency specialty	9 (22%)	2 (5.4%)	0.051
On-call duty	50 (66.7%)		
Distance from the nearest emergency department	10km [3;20]		
Distance from the nearest cardiology office	6km [1;18.5]	km [1;5]	<0.001
Training seminar for interpreting ECGs	14 (18.4%)	4 (5.3%)	0.022
Self-perceived skills in ECG interpretation	43 (57.3%)	12 (16%)	<0.001

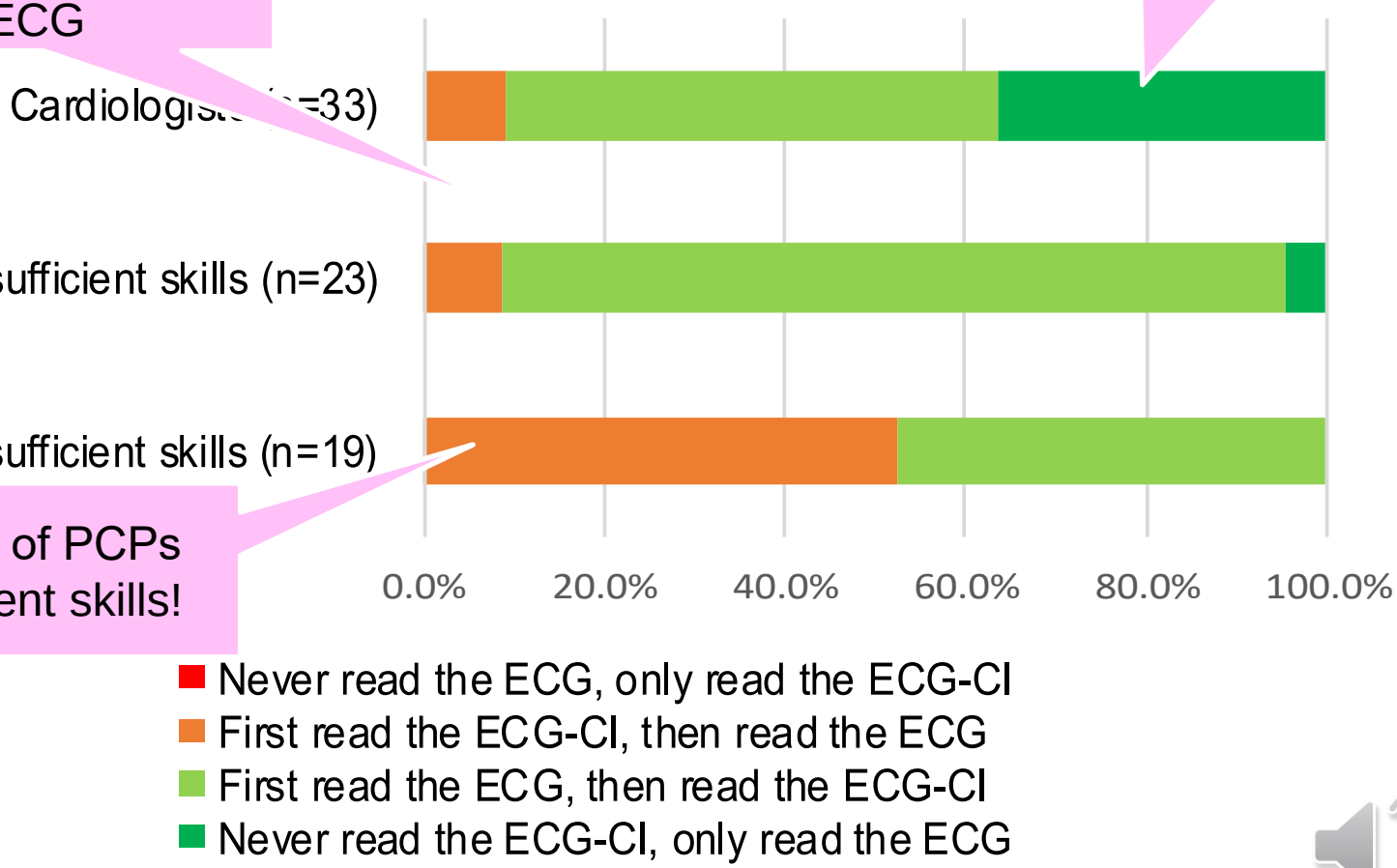
think they are more able to interpret ECGs… but only 57%

Delrot C, Bouzillé G, Calafiore M, Rochoy M, Legrand B, Ficheur G, Chazard E. Do Medical Practitioners Trust Automated Interpretation of Electrocardiograms? Stud Health Technol Inform. 2019 Aug 21;264:536-540. doi: 10.3233/SHTI190280.

Usual attitude of physicians having ECG-CI (

~9% of cardiologists and PCPs with enough skills first read ECG-CI then the ECG

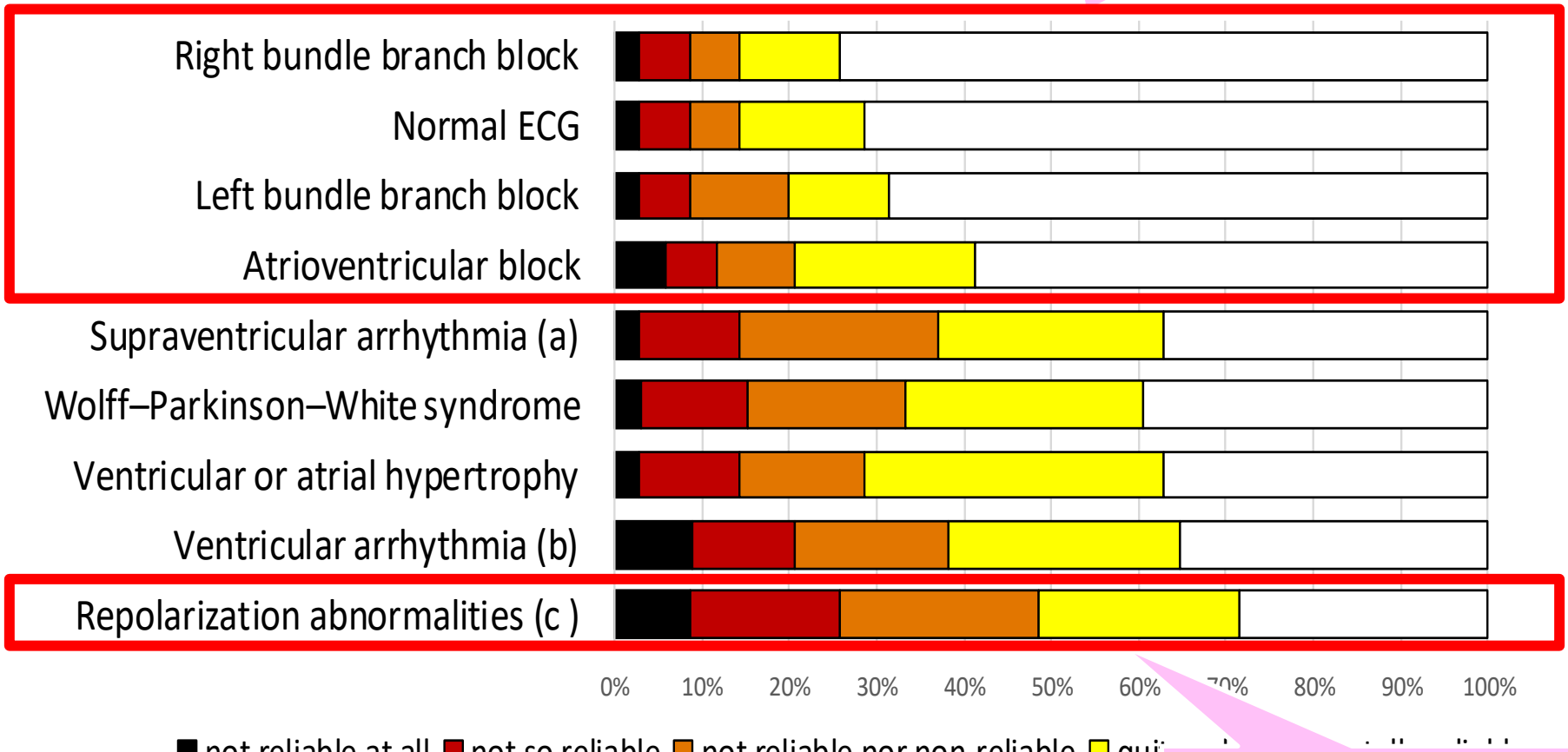
36% cardiologists refuse to read ECG-CI



…but 52.6% of PCPs with insufficient skills!

Perceived reliability of ECG-CI, by statement

Acceptable (but non perfect) reliability for normal ECG and conduction troubles



Lowest reliability for myocardial infarction!

And if remote interpretation was finally the solution?

Special thanks to:

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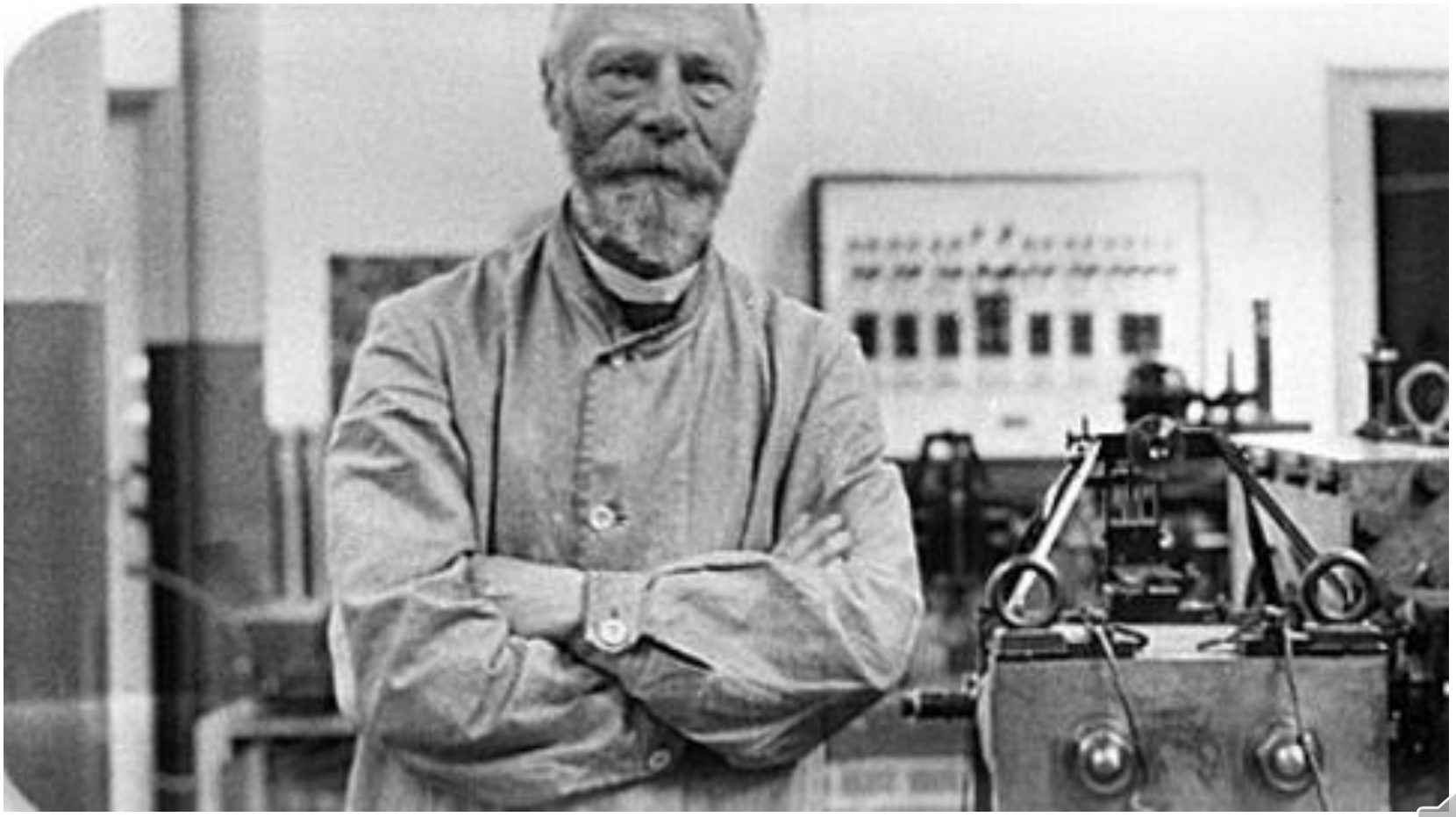
Antonio Luiz Ribeiro,

& Milena Soriano Marcolino

Willem Einthoven, ECG transmission via telephone lines, 1500m, 1906.



Minas Gerais: a Brazilian state with a highly concentrated population

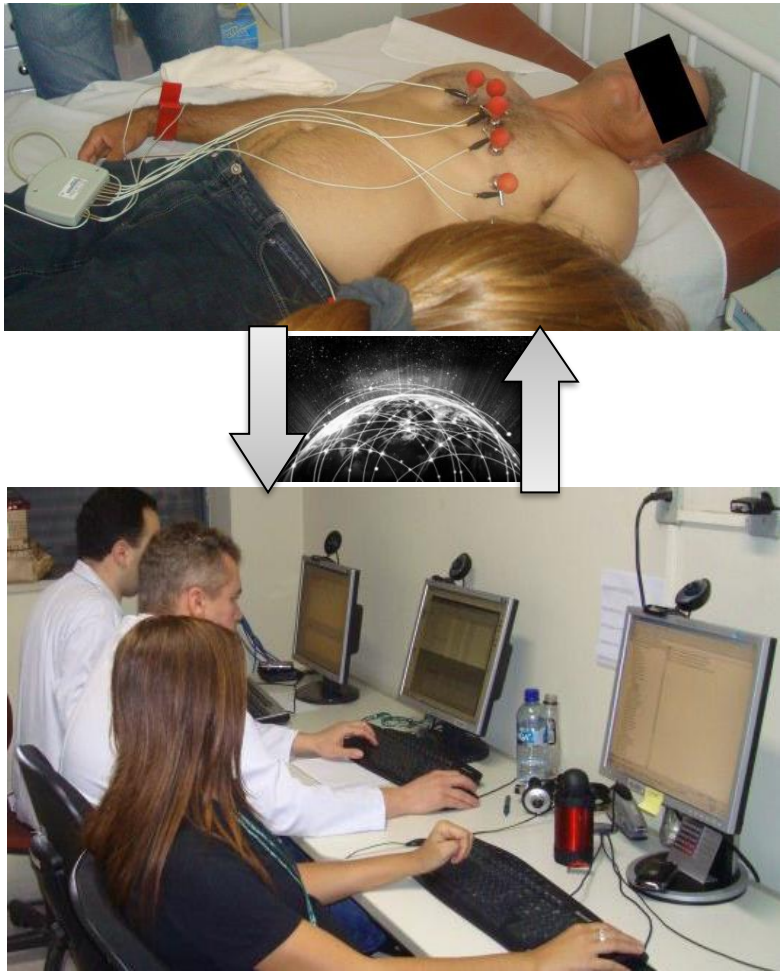
- Brazil
  - 26 states

- Minas Gerais (MG)
  - 3rd richest state of brazil
  - Capital = Belo Horizonte

- The Belo Horizonte metro
  - 26% of the MG population!
  - Good access to healthcare services

- Outside the capital
  - Mean: 25 inhabitants/km²
  - Low transport speed
  - No cardiologist

Remote ECG interpretation



- Example of Centro de Telessaúde Hospital das Clínicas - UFMG
- ~1000 remote healthcare centers
  - 1 general pracitionner, 2-3 nurses, etc.
  - ECG recording
- Web transmission
- 1 unique center for interpretation. Every day:
  - 3 on duty cardiologists
  - about 1,000 ECGs are interpreted!
  - average delay: 3 hours

Remote ECG interpretation

- Example of Centro de Telessaúde Hospital das Clínicas - UFMG
- ~1000 remote healthcare centers
  - Low-cost equipment: PC, printer, webcam
  - ECG recorder: 10 standard probes, USB link, simple data acquisition module
  - DSL internet communication
- For mobile GPs
  - Complete suitcase
  - Cell phone for data transmission over the web

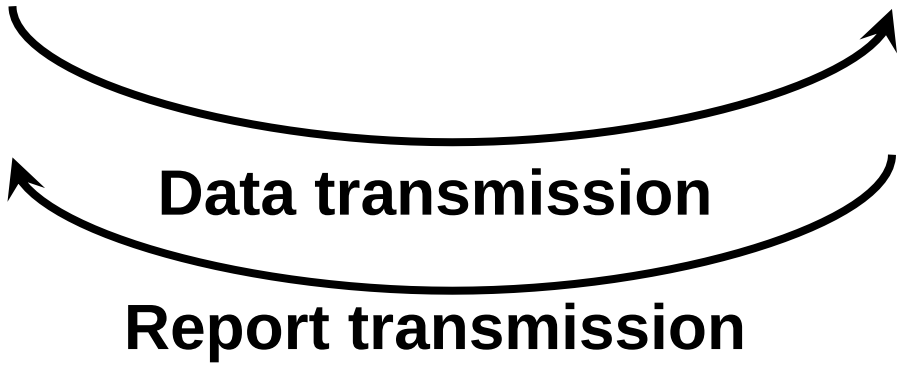
ECG: the perfect candidate for telemedicine!

Exam capture

- On the patient
- Low cost device
- Simple training: positioning the probes (nurse, GP, etc.)

Exam interpretation

- Asynchronous: no interference with the capture
- Rare skills: mainly cardiologists
- Fast interpretation



can be outsourced to a country where labour is cheaper