Using Computers to Process ECG Recordings

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Computers in Cardiology

- One of the earliest uses of computing in medicine!
  - To monitor patients in CCU and ICU
  - To diagnose certain kinds of cardiac illness and to evaluate treatment efficacy: is the treatment preventing the problem?
  - To “pace” the heart, for individuals who have arrhythmias of kinds that can’t be treated with drugs (and even to defibrillate if needed).

An example of a single QRS

- A QRS complex is the electrical signature of a heartbeat

http://members.home.nl/jvdmortel/Het%20ecg%20beoordeling.html

Electrical conduction in the heart

- The heart is controlled by two kinds of pacing
  - The normal nervous pacing involves a network of nerves that control normal heart beats
  - Beat is triggered in the “Sinus Node”
    - Then spreads through the atrium
    - After a delay, spreads down to trigger a ventricular contraction

Terminology

- A “P wave” is the electrical signal from the contraction of the atrium
  - This will be a small wave because the muscle mass involved is small
- The “QRS” wave is the signature of a ventricular contraction, and is large because the ventricles are large and powerful
- The “T” wave represents repolarization (recharging) of the ventricular muscles
  - Very rarely, one can discern a “U” wave as the cardiac nerve network recharges

Our goal?

- Capture ECG data from a patient
- Computer should locate and annotate the QRS complexes and use this data to determine heart rate and to identify abnormalities
- Sometimes, but not always, findings will be reviewed and “edited” to correct errors
- Then used by a provider as basis for care
We think of the ECG as a solid curve but the computer sees a series of voltages.

Some patients complain of faintness or other symptoms that might be due to cardiac problems. But not all cardiac problems are evident in the doctor’s office. So these tests allow the patient to go about his or her normal day.

They wear the monitor for the entire day and night. Normally also keep a log. Later the physician can later check for “evidence” of a problem at times the patient felt ill.

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What’s normal?

Not the “shape” of the waveform!

- In a holter recording, the shape seen depends on where the leads were attached!
- But a normal rhythm has
  - A regular, fairly steady heart rate between about 40 bpm and about 160 bpm
  - Changes in heart rate usually occur “steadily”
  - Waveform can vary slowly over time, but shouldn’t change “abruptly”

What is a Holter Monitor?

- A small recording device that can capture 24 or more hours of electrocardiogram data
- Size of an ipod or cell phone
- Five electrical leads connect it to sensors that are taped to the patient’s chest
- The data results in a two-channel signal with time advancing from left to right
- This signal reveals data about the patient’s cardiac function and rhythms

Notice: It has two “channels” showing the same information but from different electrical perspectives

This patient was healthy.

| PAC: “Premature Atrial Contraction”.
| An early but otherwise normal heartbeat | Looks normal (but early) in both leads | PAC: “Premature Atrial Contraction”.
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http://www.physionet.org/physiobank/database/afdb/c

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What can cause an PAC?

- Typically associated with
  - Common: Stimulants (e.g. caffeine or cocaine), heavy drinking, dehydration and exhaustion....
  - Certain kinds of nerve damage that makes the atrial network "twitchy"
  - Can't always pin down the cause and in fact, many healthy people get them – now and then

What can cause an PAC?

- Can you feel them?
  - Sometimes patient will feel a “flutter” or believe that they sometimes “skip” a heartbeat

- How are they treated?
  - Problem often resolves if the patient changes their behavior.
  - Medications can also be used for severe cases

PAC events can be quite rare

- Important issue: by what percentage must a contraction be early to qualify as an PAC?
  - Rhythm always changes a little, need to track heart rate to know what “normal” actually is
  - Usually 20% early qualifies as abnormal

But can also occur in “runs”

- A short run isn’t much different from a single isolated PAC. A long sequence is termed “Atrial Fibrillation” and can be serious
  - AFIB is associated with heart attacks.

How can you recognize noise?

- You usually know it when you see it!
  - Basically, no explanation for what you are looking at.

- But computers can have trouble doing what humans easily are able to do.... Humans see patterns; computers need to be programmed to find them

- Noise could fool a computer!
  - A big noise spike in between two normal QRS complexes.... Could “mimic” an PAC
  - But unlikely to show up in both channels...

PVC: Premature Ventricular Contraction

- The normal “sequence“ for a heartbeat is disrupted: the ventricle contracts without atrial pacing, like a twitchy muscle
  - No “P” wave, or a very distorted one

Looks abnormal in at least one lead
What causes them?

- A PVC is potentially a sign of damage to heart muscle tissue or to the nerve paths
  - Surprisingly many people experience them, including some healthy people. Many causes
  - Feels like a skipped beat... Or goes unnoticed
- When caused by damage to the heart...
  - Could be a left-over from a prior heart attack, and may not be a sign of trouble to come
  - But may also be a warning of a serious problem

Frequent PVCs are more serious

- A patient experiencing frequent PVCs will have poor blood flow as a result, may feel out of breath, tired, dizzy
- Can also be prone to blood clotting disorders and may be at risk of a heart attack

Is it noise? Or frequent PVCs?

![Graph of ECG](http://www.physionet.org/physiobank/database/afdb/)

Frequent PVCs are more serious

- A very irregular, inefficient, cardiac rhythm
- Blood flow largely stops. Classic heart attack

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So how do computers analyze a Holter ECG?

- Step one: Digitizing the signal
  - The machine needs to capture the signal, normally at 250 samples per second (an agreed standard that dates to around 1982).
  - Done directly on the collection device itself
  - Samples are integers representing amplitude
  - Thus there will be 24 hours x 250 samples per second, or 22 million data points, per channel
  - This data will be stored into a file

Ventricular “Fibrillation”

- A very irregular, inefficient, cardiac rhythm
- Blood flow largely stops. Classic heart attack

![Graph of ECG](http://www.physionet.org/physiobank/database/afdb/)

Need for a “real time” operating system

- Systems like Windows and Linux sometimes pause for brief periods to do very important stuff
  - Like scratching their, um, network interfaces
  - And while doing this important stuff, might neglect to capture data
- What will it look like if ¼ second of data is “clipped out” of a normal signal?
Data “clipped out”

- A surprisingly common issue....

What does this show us?

- We’re dealing with very sensitive data
  - It might be critical to a patient’s life
- And yet minor issues such as whether the computer is continuously instantly available for 24 hours can cause us to make mistakes!

Result?

- A “computer generated” arrhythmia
  - Could mimic a PVC or a PAC
  - Or could look like noise
- Can actually be almost impossible to “understand” by visual inspection
- Hence must use a “real time” operating system on the device collecting the data

What are these?

If you guessed “noise”...

- Correct!
  - Many holter recordings have noise on them
- What causes noise?
  - Thick, loose skin
  - Sweat can detach electrodes
  - Patient might scratch the electrode, or hit a tennis ball, or cough, or take a shower

Noise

- The computer needs to
  - Flatten the “baseline” to remove those huge swings
  - Normalize the signal so that the peaks are of a pretty steady amplitude
Filtering to Reduce Noise
- 50/60Hz noise is common (electrical machines like blenders, vacuum cleaners)
- Often must “filter” the signal to clean it up
  - Worry: When filtering we average data to smooth the noise
  - But did filtering cause other changes too?

Filtering
- Filtering makes data easier to look at but also distorts what we measured.
  - Some systems display the raw data but process filtered data.
  - Other systems display the filtered data and only show raw data if you “turn off” filtering.
- Thought questions:
  - What issues can filtering create?
  - Is there a best story? What would you do?

But we’re far from done...
- OK, we’ve cleaned up the signal
- Now how does the computer analyze it?

Finding the QRS itself
- Look for a sharp spike?
  - But noise can have sharp spikes
  - And some QRS shapes on normal ECGs are pretty “round” looking
- Use the rhythm as a hint for where to look for the QRS complex itself?
  - But a normal sinus rhythm could be as low as 30bpm and a very fast heart rate can reach 180 bpm
- Many systems make small mistakes (and sometimes they make big mistakes!)

Then what?
- Next classify the “shape” of the waveform
  - Learn what a normal QRS looks like
  - Early but looks normal => PAC
  - Early, looks weird? Call it a PVC and learn the shape of the PVC
- Why not use a “frequency domain analysis”?
  - Turns out that the mathematics underlying FFT analysis and “wavelets” don’t really apply cleanly in our setting (ECG isn’t “stationary”)
  - But even a so-so job of shape analysis helps us resist confusion due to noise

Last stage? Look for patterns
- Run of PACs? AFIB
- Two PVCs in a row? A “pair”
- Alternation of normals, PVCs?
  - Bigeminy, Trigeminy...
- Long run of PVCs? VFIB
  - (And there are others: sleep apnea, for example, is sometimes associated with serious sinus bradycardia: the heart rate drops drastically)
So what’s the take-away?

- ECG analysis isn’t really “science”
- We use sophisticated artificial intelligence...
  ... which means, a grab-bag of tricks, heuristics and rules invented by people like us
- This feels wrong, but it usually works
- Bottom line: A rigorously correct ECG analysis can’t really be done by machines. Even people make mistakes in some cases.

Machines can’t think (yet)

- A physician has a mental model of cardiac behavior and illnesses
- She can use that knowledge to make sense of the data
- A computer just applies a grab-bag of rules. It doesn’t “think” at all.

Discussion topics

- The computer can’t “understand” an ECG. Yet it is practicing medicine. Is this ethical?
- Suppose a medical center uses a computerized ECG monitor for two years. It works flawlessly and they begin to rely on it. Then one day, an “unusual” ECG waveform triggers a latent bug. The patient dies. Who was at fault?