

Patient Monitoring

SP.718 D-lab Health: Medical Technologies for the Developing World (Special Topics at the Edgerton Center)

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What is patient monitoring?

“Repeated or continuous observations or measurements of patients, their physiological function, and the function of life support equipment for the purpose of guiding and assessing the efficacy of patient management decisions, such as therapeutic interventions.”
(Gardner and Shabot)

- Automated (noise prone)
- Semi-automated (decision support, human filters)
- Manual (integrative, low-cost, traditional, subjective)
(Usually well trained, intelligent monitors!)

Who needs intensive monitoring?

There are at least 5 categories of patients who require intensive physiological monitoring:

1. Patients with unstable physiological regulatory systems (e.g. a patient with impaired respiratory system)
2. Patients with suspected life-threatening conditions (e.g. acute MI)
3. Patients at risk of developing a life threatening condition (e.g. major post-operative patients)
4. Patients in critical physiological state (e.g. trauma/shock)
5. Mother and baby during the labor and delivery process

Reasons for monitoring & storing data

- For decision support and management of patient
- To allow the review of historical data
- To organize and allow concise reporting (billing?)
- To allow data mining for retrospective studies
- To measure severity of illness and provide optimization of resource allocation
- Automated data fusion, and 'conflict resolution'
- To allow quality control through assessment and evaluation of performance (outcomes, LOS, infection rates, costs, etc)



Most important parameters to monitor

- **HR (heart rate),**
- **SpO₂ (oxygen saturation),**
- **Systematic pressures** (SSAP, systematic systolic arterial pressure; SDAP, systematic diastolic arterial pressure; SMAP, systematic mean arterial pressure),
- **Core temperature** (inside the heart)
- RR (respiratory rate),
- ECG (electrocardiogram),
- Peripheral temperature (on top of the instep),
- CI (cardiac output index, CO/m²),
- CVP (central venous pressure),
- Pulmonary pressures (PSAP, pulmonary systolic arterial pressure; PDAP, pulmonary diastolic arterial pressure; PMAP, pulmonary mean arterial pressure),
- svO₂ (oxygen saturation in the lung artery),
- ETCO₂ (outcoming carbon dioxide),
- FIO (ingoing oxygen),
- Diuretics,
- Drip drugs (type and rate)
- Bolus (oral/hypodermic) drugs
- Patient's weight,
- Fluid balance (ingoing and outcoming fluids)
- Intra-cranial pressure (ICP)
- Electroencephalogram (EEG) ... seizures



Other important information

- X-rays (masses, pneumonia, pneumothorax, fracture)
- MRI & CT scans (stroke)
- Ultrasound diagnostics (fluid, labor)
- Admit note/patient history
- Nursing progress notes
- Problem lists
- Alarms
- Events/procedures/interventions
(intubation, surgery, transfers ...)
- Laboratory tests
- Movement & consciousness (GCS, actigraphy)



Equipment landscape

- Not many large advances since the 70's
 - Except CT, MRI – very expensive

Photo removed due to copyright restrictions.

"Doctor and Nurse with ICU Monitoring Equipment, 1965."

<http://www.uphs.upenn.edu/paharc/collections/gallery/departments/ICU.html>

- Bedside monitors cost \$10-50k
- Robust electronics
- Robust connectors!!! (Most important)
- ... but proprietary connectors, not cheap!

Photos of connectors removed
due to copyright restrictions.

Variety of monitoring situations

| <u>Monitoring Situation</u> | <u>Developed</u> | <u>Developing</u> |
|-----------------------------|------------------|--------------------|
| Rural | light (homecare) | none |
| Outpatient / Home | light | none |
| General Wards | light | little/none |
| Paramedics | light/variable | little/none |
| E.R. | light/variable | little/none |
| O.R. | hyper-intensive | some/none |
| I.C.U. | Intensive | some if ICU exists |

(Generalizations, not always true, particularly in private health care)



Equipment in US hospitals

- Sensors
- Monitors
- Data transmission
- Feedback

Photos removed due to copyright restrictions.
IV drips, ventilators, ECG, BP, PPG, respiration and
blood gas monitors, medications, UPC bar code.

Outpatient/home monitoring

Photos depicted home monitoring equipment removed due to copyright restrictions.

[Randomized prospective trials have shown that 12% to 75% of all readmissions can be prevented by patient education, pre-discharge assessment, and domiciliary aftercare.

See: Jochanan Benbassat; Mark Taragin. "Hospital Readmissions as a Measure of Quality of Health Care Advantages and Limitations." *Arch Intern Med.* 2000;160:1074-1081.

<http://archinte.ama-assn.org/cgi/content/full/160/8/1074>

Technology & Infrastructure in Developing Countries

- Old legacy hardware & instruments
 - Generally paper notes, static information
 - Poor communication channels
 - Poor drug storage and supply
 - Poor waste disposal
 - Poor transport
 - Intermittent electricity
 - Information shortage
 - Skills shortages
-
- See Malkin 2007
(assigned reading)

Photo removed due to copyright restrictions.
Fig. 1 in Robert A. Malkin. "Design of Health Care Technologies for the Developing World." *Annu Rev Biomed Eng* 9 (2007): 567–87.
<http://dx.doi.org/10.1146/annurev.bioeng.9.060906.151913>

Ad-hoc medical facilities

- Free market
- Out of calibration



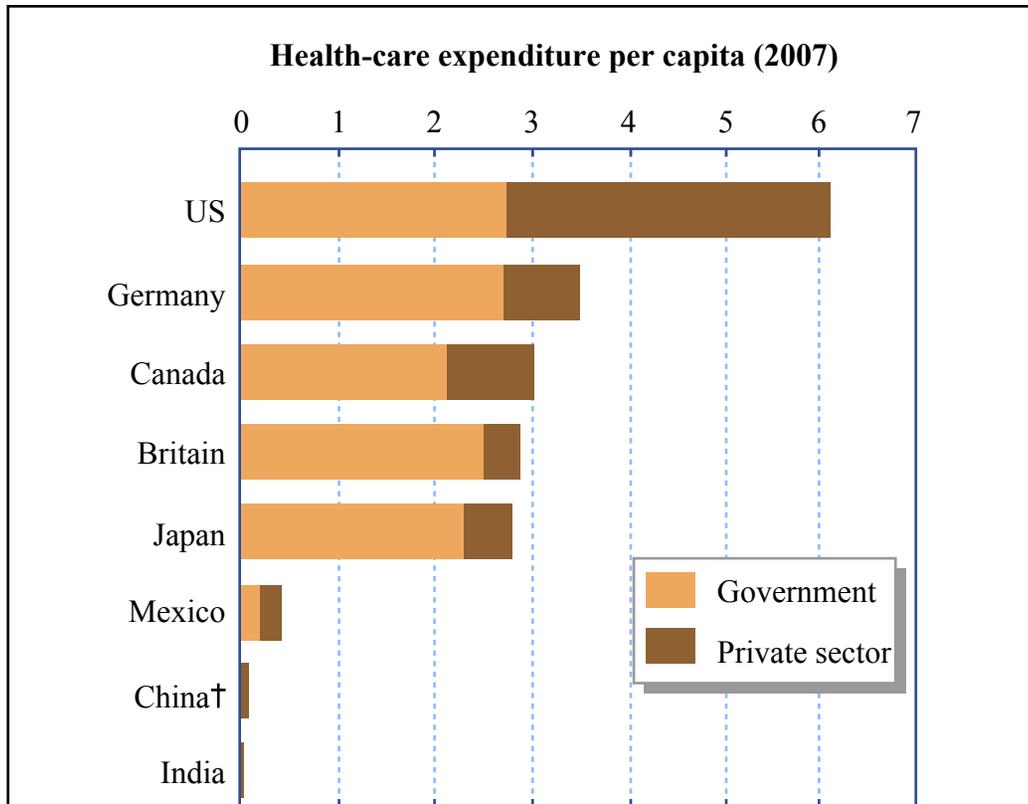
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Health care delivery problems

- i. Lack of equipment for diagnostics and monitoring
- ii. Lack of money
- iii. Lack of data to understand what are the problems and what equipment and skills are available
- iv. Lack of rapid transmission of data
- v. Lack of co-ordination between different health organizations (NGOs, govt., religious organizations, etc.)
- vi. Lack of servicing/calibration
- vii. Lack of skilled health care workers
- viii. Donated equipment can actually cost money (storage costs when unused)
- ix. Spare parts are expensive and take a long time to order
- x. Disposal of dirty equipment is problematic

Health Care spending Per Person 2007

- Per capita health care spending in developing countries is ~100 times lower than developed countries



Source: The Economist,
October 18, 2008; data
from World Health Organization

* At average exchange rates
† Excludes Hong Kong and Macau



6 minutes per patient!

- Rapid & accurate evaluation and information retrieval needed



Technology for development?

- Medical monitors
- Surgical equipment
- Fixed voice telecommunications
- Internet / Peer-to-Peer
- Communication devices: cell phones *et al.*
- Computing devices: PCs, PDAs
- Sensor monitoring: Cameras, RFID
- Conventional media (TV, Radio, Walkie Talkies)
- Infrastructure (electricity, transport, ...)



Trends in technology

- Explosion of cell phone ownership and networks
- Health monitoring, diagnosis & inventory tracking
- Delivery of refurbished/recycled equipment
- Mobile incinerators

Image removed due to copyright restrictions.
Map showing Honduras, El Salvador and Guatemala.

World Mobile (GSM) Coverage - Jan 2005

Images removed due to copyright restrictions.
World maps for Jan. 2005, Jan. 2007 and Jan. 2008,
showing rapid growth of coverage.
See <http://www.coveragemaps.com/gsmposter.htm>.

What is changing?

- **Apart from Coca Cola, telecommunication companies are the only industry to be able to delivery cheap and reliable services and equipment to developing countries!**
- **Over 80% of humans live within range of a cell phone tower**
- **Over 2 billion cell phone subscriptions worldwide**
- **Cell phone usage increasing up to 30% annually***
- **Cost per kilobyte dropping every year**
- **Cost of hardware dropping every year**
- **Cost of computation dropping rapidly every year**
- **Integrated sensors increasing every year
(Camera, Video, Accelerometer, GPS, larger screens)**
- **Battery storage technology improving every year**

* (India)



Why particularly cell phones?

- Don't think of it as a phone – it's a mobile hand-held computer with integrated communication and sensors.
- What's unique about this hardware for medical care?
 - **Multi-functional and self-contained:** but parts are no use for other devices; user will not strip it for battery or other uses.
 - **Easy to charge** even when no grid electricity available (can even use wind-up generators),
 - **Easy to hide**, disguise and keep safe (in pocket),
 - **Interchangeable & standardized**,
 - **Easy to replace** – plenty of supply,
 - **No proprietary cabling** to replace (wireless communication)
 - **Significant computational power** in one device! – **A.I.?**
 - **Humans want (need) to communicate** – they will ensure that the device is always working and are highly motivated to have it repaired quickly if it is their primary method of communication!



Electronic Medical Records (EMRs)

- How to track health problems and provide relevant treatment?
- Completeness of record?
- Synchronization Problems
- Privacy concerns

Categories of data collected in PIH HIV-EMR

- Patient demographics
- History of presenting complaint
- Previous treatment and any adverse events
- Symptoms
- Physical examination
- Laboratory investigations
- Social circumstances, housing, occupation
- Drugs
- Narrative text is also allowed in some categories such as clinical history and assessment

See Gari D Clifford, Joaquin A Blaya, Rachel Hall-Clifford, Hamish SF Fraser
Medical information systems: A foundation for healthcare technologies in developing countries BioMedical Engineering OnLine 2008, 7:18 (11 June 2008) .
<http://www.biomedical-engineering-online.com/content/7/1/18>



Example 1: Mobiles Reducing Infant Mortality

*

- Pesinet project in Mali and Senegal
- Local staff transmit infants' weights and symptoms via a Java app on their cell phones
- In Senegal, infant mortality rate fell from 120 per 1000 to 8 per 1000
- Self-financing, after installation costs covered by donors



* Reported July 20, 2007 by Balancing Act, Africa, issue 364

Example 2: Cervical cancer screening

Issues:

- **Skills** to read images of cancer are **limited** (e.g. menopause looks like cancer)
- 2nd opinion requires a **multi-step process** to send image & receive feedback
- Patient may have left clinic (and never return) by time diagnosis arrives
- Images can be out of focus over/under-exposed or contain lighting artifacts
- Patient's previous/future visits are hard to track

Solutions:

- Replace existing cameras for taking and storing images
- Provide instant transmission of images for remote diagnosis
- Archive data for follow-up and quality audits
- (Semi) automated diagnostics
- Cell phone can train care workers:
 - tell user to re-take image (quality)
 - Tell user where cancer is

Image removed due to copyright restrictions.

Diagram of cervical cancer stages,

http://www.preventcervicalcancer.ie/what_causes_it.asp

Considerations for design

- Cost!
- Local skills & materials for manufacture and supply
- Supply chain for delivering product and replacements
- Consumables (electrodes, bandages)
- Sanitary disposal of blood products
- Robustness
- Ease of use – who can use it?
- Reusable vs disposable components?
- Local power supplies?
- Reusable vs disposable components?



Not just equipment ... anthropology too

- Survey needs of population in unbiased manner
- Track follow-up and performance metrics
- Design human-device interaction modalities
- Assess whether people still *want* to use technology after the excitement wears off
- Help implement and maintain programs in a culturally acceptable manner

Multi-tasking devices to save money/equipment & improve estimates

- An oximeter can provide:
 - O2 sats
 - HR
 - Respiration
 - Cardiac Rhythm (basic)
 - Activity
- An ECG can provide:
 - HR
 - Respiration
 - Cardiac Rhythm (advanced)
 - Activity
- Respiration information (to detect apnea or hyperventilation) can be derived from:
 - ECG (each lead, and in 3 different ways)
 - Pulse oximeter
 - Blood pressure
 - Impedance pneumogram
 - Accelerometer
 - Temperature probe (on nose)



So what can we do right now?

- Low cost pulse oximeter for monitoring HR & SpO₂
- In the O.R., I.C.U., general ward, E.R., during transportation (for stability), and in the field (triage?)
- How can we re-engineer existing cheap electronics to monitor these parameters in a simple and efficient way?
- What do we do with the data (clinically)
 - Tachycardia/bradycardia
 - Asystole
 - Rhythm? (Atrial?)
 - OR desaturations
 - Apnea
 - Respiration
 - Activity
 - Heart sounds (audio) –valve problems?



Summary

- Internet-based systems provide efficient medical result reporting
Technology can increase efficiency, save lives and provide more timely care *if done correctly*
- **Sustainability**; existing infrastructure? What's coming next? Who pays?
- **Local relevance**? Power requirements, supply channels, (storage, transport, weather)
- **Training / education** in short supply
- **Tracking supplies and needs** is important
- **Performance metrics**? Difficult but not impossible:
 - Costs
 - Compliance
 - Frequency of disease
 - Relapse

Readings

- Gari D Clifford, Joaquin A Blaya, Rachel Hall-Clifford, Hamish SF Fraser
Medical information systems: A foundation for healthcare technologies in developing countries *BioMedical Engineering OnLine* 2008, 7:18 (11 June 2008)
- Robert A. Malkin, **Design of Health Care Technologies for the Developing World**, *Annu. Rev. Biomed. Eng.* 2007. 9:567–87
- Atul Gawande, **Annals of Medicine: The Checklist; If something so simple can transform intensive care, what else can it do?** *New Yorker*, December 10, 2008 http://www.newyorker.com/reporting/2007/12/10/071210fa_fact_gawande
- Reed M. Gardner and M. Michael Shabot, **Patient Monitoring Systems** Ch 17 in “*Biomedical Informatics; Computer Applications in Health Care and Biomedicine*” Edited by Edward H. Shortliffe and James J. Cimino

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