Future Challenges in Medical Informatics
- Ubiquitous Healthcare IT and Omics-based Medicine-

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Challenges in Medical Informatics?

- Target disciplines we should tackle in coming age to extend and deepen our medical informatics field?
- Medical Informatics, Medical IT
  - It started with hospital-based technology primarily to implement clinical system.
  - Now, new paradigms of medicine are to be considered with deep relations to “information”, such as, genomic medicine, standardization of medicine, ubiquitous healthcare IT and so on.
- Various Challenges are there, but we should think about them in relation to questions of what will be the key concept of future medicine.
  - Key paradigm of 21th cent. Medicine
Paradigm of Medicine
Current Medical IT Targets

Current Major Concepts in Medical IT
Interoperable EHR, CPG-based Diagnosis/Therapy

“Standardized” Medicine
Objective criteria to attain and share “quality of medical care” to have equal opportunity to receive best medical practice

Evidence-based Medicine

Next Generation Concepts for Medical IT

Evidence-based Medicine, Clinical Practice Guideline

Standardized Medicine

Individualized Medicine

Genome-based Medicine, Genetic Polymorphism

“Broader”

Ubiquitous HealthCare

“Deeper”

Medical care and Preventive health Integration
### Road map of Healthcare IT

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
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<tbody>
<tr>
<td><strong>Standardization of Medical Care/EHR</strong></td>
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<tr>
<td>EBM, Clinical Practice Guideline, Interoperable EHR</td>
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<td><strong>Genome/Omics-based Medicine</strong></td>
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<tr>
<td>PGx, Individualized Medicine, Systems Medicine</td>
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<td><strong>Ubiquitous Healthcare</strong></td>
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<td>RFID, Ubiquitous HIS, Home healthcare</td>
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### Medical Informatics in Genome/Omics based medicine
A new discipline of Medical informatics supports the clinical realization of Genomic Medicine.

Genomic Medicine and Informatics

Genomic Medicine

New!

Vast amount of Genomic/Molecular data

Clinical-Patho physiological ordinary data

Genome Medical Informatics

(Clinical bioinformatics)

Should be supported
What kind of new possibility does genomic information bring about to clinical medicine?

**well-known, most important contribution of genomic medicine**

**Medical Care can be Individualized**

**Tailor-made (individualized) medicine**

- **Genomic Polymorphism**
  - Human genome contains individual differences
  - **SNP**
    - Single Nucleotide Polymorphism
    - One for 1000 bases, 0.1%, 3M to 10M bp
  - **Other types** Micro-satellites, VNTR

- **Individualized Medicine**
  - **Disease susceptibility**
  - Personalized genomic typing
  - **Drug responsibility**
  - Pharmacogenetics/genomics
  - **Hapmap project**
  - Haplotype DB project

- **Genotype**
- **Chromosome**
- **Haplotype**
- **Chromo-some**

- **Genome**
- **Aa Bb**
- **Genotype**
- **haplotype DB**
- **A b C d**
- **Haplotype**
- **Chromo-some**
Drug will be administered depending on the individual genotyping

- Pharmacogenetics/genomics
  - Individual difference in drug response sometime causes serious side-effects
  - Avoid useless drug administration (side-effect)
- DNA pre-diagnostic test for drug responsibility
  - FDA guidance recommends
  - Drug metabolism enzyme CYP450 60kinds
  - Herceptin for HER2 receptor for breast cancer

Tailor-made Drug Administration

Drug effects vary among individuals

What to do to support the genomic medicine

Genome Medical Informatics

To adapt **clinical information system** to **genomic medicine**

- to organize clinico-genomic patient information
  - clinico-genomic ontology, genomic EMR
- to develop genomic healthcare information system
  - genomic preventive medical care
An example of Challenges in Genome Medical Informatics
-Clinico-genomic ontology-

Ontology mismatch between Clinical thinking and Omics

- Ontology
  - System of Controlled vocabulary
  - Concepts and relations which support genomic medicine
- Excellent ontologies separately developed in both fields
- Mismatch
  - Between Clinical ontology and Bio-ontology
Clinical thinking and “Omic space”

- Clinical thinking (Top down)
  - Organs and diseases are units of concepts
  - Traditionally disease is defined on pathological, morphological base
  - Relations are causal, attributable, consequential

- Omics world (Bottom up)
  - Molecular function and their functional relation to other molecules
  - Products of gene expression are units of concepts

Integrated clinico-genomic ontology

Comprehensive framework to join these two paradigms is required.
“Pathway/network” will be the basic entity
Genomic Medicine is now revolutionarily changing Omics-based medicine

So far we are concerned with current state of GMI, But

Omics data

**Genome/ics:** whole genetic information
**Transcriptome/ics:** whole mRNA
**Proteome/ics:** whole functioning proteins
**Metabolome/ics:** whole metabolites
Then, what kind of new possibility does omics information bring about to clinical medicine?

Other than the individualization information, omics information provides detailed and comprehensive molecular information about current diseased states.

Omics are provided by high-throughput equipments: DNA chip/microarray (transcriptome), TOF-MS (proteome) etc.

- **Detailed Information**
  - for subtypes/detailed structures of disease
  - Unobservable from conventional clinico-pathological tests
  - Detailed Diagnosis and Accurate Prognosis,
  - Early detection of disease

- **Comprehensive Information**
  - Wholistic understanding of disease
  - Leads to Systems pathology
Omics data provides clinically and pathologically unobservable information.

Abnormality in Molecular Network

Differences of Prognosis, Disease Course

Pathology, Tissue
Same looking

Same in pathology and clinical symptom
But different in Prognosis

Breast cancer

For example

What is difference of **Omics-based Medicine** from Conventional Genomic medicine, or “Tailor-made Medicine”
Omics-based Medicine

What kind of approach is necessary to fully utilize the Omics data for clinical diagnosis/therapy?

I propose.....
“Systems pathology”

Comprehensiveness of Omics data makes possible to understand a disease as an integrated whole. Try to find disease mechanism behind the omics data.

- System theory of disease
- Disease: systems failure of bio-process

**Systems Pathology**
Understand disease as disturbed systems

Normal pathway to Disease Pathway

Disease organizes itself → Formation of Disease pathway

The first key concept of systems pathology: Disease is hierarchically organized integrated system

**Clinical Level**

- Whole Body Level
  - Whole Body Coordination
    - neural, endocrine regulation
  - Top-down Causality
    - Tissue-Morphological abnormality
    - Pathological cell population
    - Cell-cell communication
    - Pathological cell

**Tissue-Pathology**

- Integration
- Information flow
- Morphological Constraint

**Cellular Level**

- Signalling network
- Gene regulatory net
- Metabolic network

The comprehensiveness ofOmics data makes it possible to understand a disease as an integrated whole. Try to find disease mechanisms behind the omics data.
Example: Hypertension

- Blood pressure raises by some abnormal supporting mechanism at early stage
  - Neural regulation
  - Hormonal regulation
- But after several months, if this condition is sustained, the genetic activity begins to start capillary vascular remodeling to sustain hypertension (adaptation by gene expression)

What does Omics-based Medicine bring about to clinical medicine

Individualization of Healthcare
Specially drug administration
Comprehensive (system) understanding of disease
With omics data and systems approach
Road map of Genome Medical Informatics

Road map of Information system for genomic medical informatics
Ubiquitous Healthcare IT

Healthcare IT Environment
where Anyone can receive Best Medical Care
“Anywhere, & Anytime”

Extension of Healthcare IT

From Conventional HIT
build on the wired network information system

To open/distributed environmental HIT
build on the wireless/open ad-hoc network
Concept of Ubiquitous Computing & Network

From Medieval Theological Concept “God exist anywhere” (Xerox Mark Weiser 1986)

Computer chips and networks are embedded in the daily environment so that users utilize them without any consciousness where they are.

- Invisible
- Embedded discernibly in the environment

Distribution of Computing into the Environment

Innovative Concept of Ubiquitous IT in the human commitment to his environment

Conventionally

Human → World

- Absolute Intelligence of human
- Full Information/knowledge
- Recognition → act

Intelligentize Environment

Ubiquitous

Human → Environment World

Sharing of Information/knowledge
Key Concepts of Ubiquitous IT

- Autonomous
  - Unconscious, no need for human operation
- Context Awareness
  - Works depending on the situation

Sharing of the information and responsibility with environmental computing and monitoring

Symbiosis between human and machine intelligence

Conscious-free
Safe and Secure life

Ubiquitous Healthcare IT

Application of Ubiquitous IT To Healthcare

"Ubiquitous Hospital IS"
Total IT-ization, Prevention of Medical Error

Emergency, Disaster IT
Ad-hoc distributed ubiquitous network

Ubiquitous Home Healthcare
IT-ization of Home Healthcare
"Ubiquitous HIS" is the 4th generation of HIS

Ubiquitous Hospital Information System

- Excess-responsibility of Medical personnel
  - Should be liberated from Myth of Infallibleness
- "To err is human" (IOM report)
  - Deaths from medical error: 44,000 to 98,000 (The 6th cause of death in US)
  - Cannot prevent by human efforts such as repetitive confirmation or checklist

Intelligentize Total Hospital Space
Automatically support the prevention of medical error by environment intelligentization
Ubiquitous IT-ization of Hospital

Total IT-ization of Hospital

IT-ized Gap still remains in conventional HIS/EMR

Prevention of Medical Error

Intelligentization of medical practice environment

Generations of Hospital Information Systems

The 1st generation Departmental Systems

~75 Accounting, Financial system
Laboratory, pharmacy

The 2nd generation Order-entry systems

~85 Labo test order
Drug administration order

The 3rd generation EMR (Electronic Medical Record)

~95 Clinical Findings
image, schema, critical path
Limitation of Conventional HIS/EMR-S

- Conventional Information System
- Field of Medical Practice

Physician $\rightarrow$ injection order $\rightarrow$ Nurse $\rightarrow$ Injection $\rightarrow$ Patient

Conventional HIS

Next generation HIS

- Extend the information system to span the IT-net to cover the field of medical practice

HIS/EMR-S $\rightarrow$ Intelligent Space

Initial trial

Recording of Execution by Bar-codes
- Nurse $\rightarrow$ Injection $\rightarrow$ Drug $\rightarrow$ Patient Wrist Band
  (International Medical Center of Japan POAS)

But Barcode: not autonomous and without multiple recognition

Expectation for IC-tag, RF-ID
4th generation HIS
Ubiquitous Hospital Information System

- EMR + Barcode-based recording
- EMR + RFID-based recording
- EMR + RFID + Ubiquitous Intelligentization

EMR + Hospital Ubiquitous IT
Stages of Ubiquitous IT-ization

- Elemental stage: Automatic Identification
  - Automatic Identification of Objects
    - Drug and Medical material, Patient by RFID
- Advanced stage: Environment Intelligentization
  - Ubiquitous Monitoring of
    - Patient Pathophysiological State (Vital sign etc)
    - Patient Physical/Behavioral State (Location, Movement etc)
    - Medical Staffs’ Medical Practice (Location, Acts)
  - Sensor-attached IC-tag for monitoring patient/staff information
  - Intelligentization of Hospital Environment
    - Administration of hospital space

Elemental Stage: Identification

1. Efficient SCM
2. Prevention of Medical Error

![Diagram of Elemental Stage: Identification with IC tag, Reader/writer, and patient wrist band with Akita University Hospital logo, drug, material, and specimen images.](image-url)
Smart Medicine Cabinet

Monitors the medicine that is placed in or taken out by a patient or pharmacist and displays information about prescriptions, incompatibilities or recalled drugs.

Department of Computer Science
Institute for Pervasive Computing,
Swiss Federal Institute of Technology Zurich

Smart Surgical Kit

The usage of bandages and swabs during a surgical operation is monitored and the usage status is displayed to avoid leaving any operation tools in the patient.

Department of Computer Science
Institute for Pervasive Computing,
Swiss Federal Institute of Technology Zurich
Intelligentization of Total Hospital Space

Total IT-ization of Hospital = Conventional HIS/EMR +

Intelligentization of Hospital Space

Ubiquitous Position Sensing

- Location-sensor
- Ubiquitous Motion Monitoring
  - Efficient administration of staffs in ER · ICU
  - Administration of clean area and infectious space
  - Space recognition and Tag-based identification
IntraHospital Location Tag

Monitor

Active Tags

Monitoring Patient Vital sign

Temperature sensor
Respiration sensor
ECG sensor
pCO₂, pO₂ sensor
Other Vital sign sensor

RFID
Active, passive
Smart stretcher

Continuous monitoring of vital signs

Automatic vital sign monitoring

transmitter

Wireless Network

receiver

transfer

Hospital LAN

Air-matt sensor

Instrumentation

Agent Processor
IP-address: 192.168.0.1
Subnet mask: 255.255.255.0

Wireless Lan

Wireless Lan adopter
Zigbee Network for Position Detection

Time series signal of vital sign
Alert systems

Smart stretcher
Respiration Wireless Monitor

PDA Monitoring Graphs Menu

State report

Patient Information

Zaurus SL-B500

06/ Linux(R) ( Embedded(TM) )
Continuous Location monitor of smart stretcher
(Monitor Image)

Home Healthcare IT
Home Healthcare IT

Virginia University

WWBAN: Wearable wireless body area network (Mayo)

Home Healthcare Devices
Structure of Medical Information Sphere

Regional Core Hospital

Other Regional Core hospital

Medical Intelligent Space

Clinics

Clinics

Clinics

Clinics

Medical Information Network

Medical Intelligent Space

Medical Intelligent Space

Medical Intelligent Space
Medical Intelligent Space

**HTTH**: Hospital to the Home

- **Intensity and distribution of MI**
  - Operating room: Most dense MI-Space
  - ICU, CCU, Ward, Outpatient clinic, Home care

### Intensity and Distribution of Medical Information

- Operating room
- ICU, CCU
- Ward
- Outpatient clinic
- Home healthcare
Future of Ubiquitous HIT

Road map of Healthcare IT
Thank you for attention