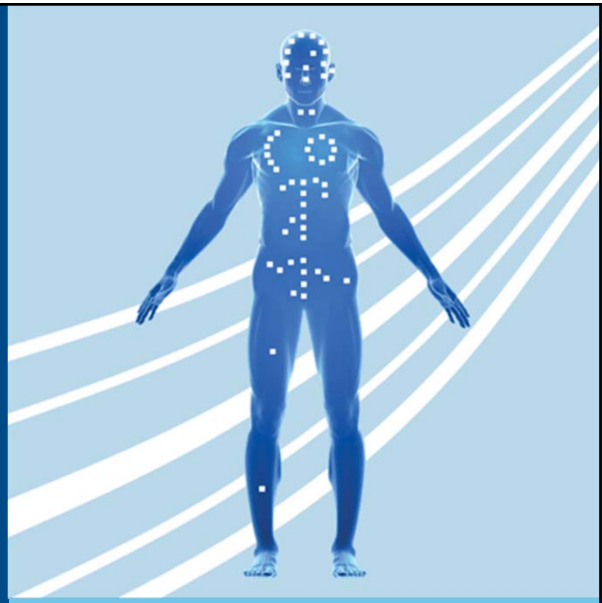
THE POTENTIAL OF THE DIGITAL TWIN AS A DISRUPTOR OF HEALTHCARE: PERSPECTIVE FROM MEDICAL DEVICES



MARK PALMER, MD, PHD
DISTINGUISHED SCIENTIST
STRATEGIC SCIENTIFIC OPERATIONS

Medtronic
Further, Together

DIGITAL TWINS
DEFINITION

DIGITAL TRANSFORMATION → **AS-MANUFACTURED MODEL(S)** + **REAL-WORLD DATA**

ACTIONABLE INFORMATION

- Physics-based Models
- Reduced Order Models
- Statistics
- AI/ML

MANUFACTURED ASSETS

- Performance optimization
- Preventative Maintenance
- Planned replacement of parts
- Enhancements
- Planned obsolescence/retirement

DIGITAL TWINS
DEFINITION

DIGITAL

AS-MANUFACTURED

REAL-WORLD DATA

HEALTHCARE

- Optimize health
- Predict and prevent adverse events
- Planned interventions
- Extend quality of life
- Extend life

- Physics-based Models
- Reduced Order Models
- Statistics
- AI/ML

MANUFACTURED ASSETS

- Performance optimization
- Preventative maintenance
- Planned replacement of parts
- Enhancements
- Extend service life

DIGITAL TWINS IN HEALTHCARE
"HOLY GRAIL"

CLINICAL OBJECTIVES

- Optimize health
- Predict and prevent adverse events
- Planned interventions
- Extend quality of life
- Extend life

MODIFIABLE FACTORS

- Diet
- Exercise
- Sleep
- Environment

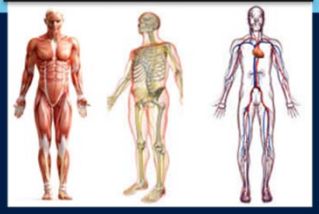
- *Medication*
- *Therapy*
- *Surgery*
- *Implantables*

PREDICT IMPACT ON PHYSIOME

DIGITAL TWINS IN HEALTHCARE
CURRENT PERSPECTIVES

PHYSICAL SCIENCE + **DIGITAL THREAD** + **DATA SCIENCE** = **DIGITAL TWIN**

Anatomy & Physiology



Use Conditions

Physics of Device

Electronic Health Record

Sensors

Internet of Things

Machine Learning

Statistical Analysis

Big Data Analytics

Digital twins exist at the nexus of physical engineering, data science, and machine learning, and their value translates directly to measurable business outcomes.*

**The Digital Twin: Compressing time-to-value for digital industrial companies*, GE

DIGITAL TWINS IN HEALTHCARE
CURRENT PERSPECTIVES

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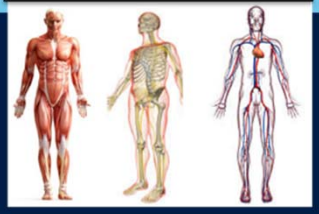

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IF THIS IS OUR FOUNDATION, HAVE WE ALREADY FAILED?

Largest sources of data is coming from individuals when they are at most challenging state of health

DIGITAL TWIN IN HEALTHCARE: CHALLENGES

1. DEFINING THE REFERENCE STATE

PHYSIOME

- Genome
- Transcriptome
- Proteome
- Metabolome
- Morphome

- *Individuals differ at every level of their physiome*
- *Differences impact how they respond to modifiable factors*
- *Changes over lifetime*

EVIDENCE BASED MEDICINE*

- Roots in clinical education
- Goal: reduce variability in resources and outcomes
- Ideally generated from Randomized Control Trials
- Analysis assumes "statistical homogeneity"
- Trials do not map well to real world (bias, tails)

*2012 De Leon, "Evidence-Based Medicine versus Personalized Medicine: Are They Enemies?"

MODIFIABLE FACTORS

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PERSONALIZED MEDICINE*

- Roots in pharmacology
- Goal: Pharmacogenetics for tailoring of drugs
- Function of ~ 33% of genome still unknown
- Role of gene-gene interactions uncertain
- Assumes "statistical heterogeneity"
- Designing and funding RCT is challenging

DIGITAL TWIN IN HEALTHCARE: CHALLENGES

2. THE DATA (MINIMIZE INTERACTION WITH HEALTH SYSTEM)

CLINICAL ANALOG

- Optimize health
- Predict and prevent adverse events
- Planned interventions
- Extend quality of life
- Extend life

DATA STREAMS

- Diet
- Location/GPS
- Activity monitors
- Some vitals
- Sleep monitors
- Biomarkers

- *Medications*
- *EHR*
- *Vitals*
- *Labs*
- *Imaging*
- *Biomarkers*
- *Genetic analysis*

MODIFIABLE FACTORS

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- Are the existing clinical measurements optimal for predicting health?
- How do we generate accessible and affordable streams of data?
- How to ensure data quality? (eg: bad sensor placement)
- Majority of variables that define physiome are inaccessible
- Reliance on longitudinal "health record"

DIGITAL TWIN IN HEALTHCARE: CHALLENGES

3. DEFINING THE DISEASE OR ABNORMAL STATE

PHYSIOME

- Genome
- Transcriptome
- Proteome
- Metabolome
- Morphome

- *Individuals differ at every level of their physiome*
- *Differences impact how they respond to modifiable factors*
- *Changes over lifetime*

MODIFIABLE FACTORS

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- How to manage genotypic expression of disease risk?
- How to manage genotypic expression of disease in absence of phenotype?
- Normal range for one individual may be pathological for another
- Time scale of onset of disease
- Time course of the disease

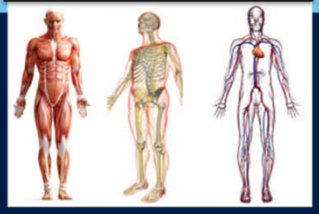
CHRONIC DISEASE

DIGITAL TWINS IN CHRONIC DISEASE

A NEAR-REAL-TIME LINKAGE BETWEEN PHYSICAL AND DIGITAL WORLDS

PHYSICAL SCIENCE + **DIGITAL THREAD** + **DATA SCIENCE** = **DIGITAL TWIN**

Anatomy & Physiology



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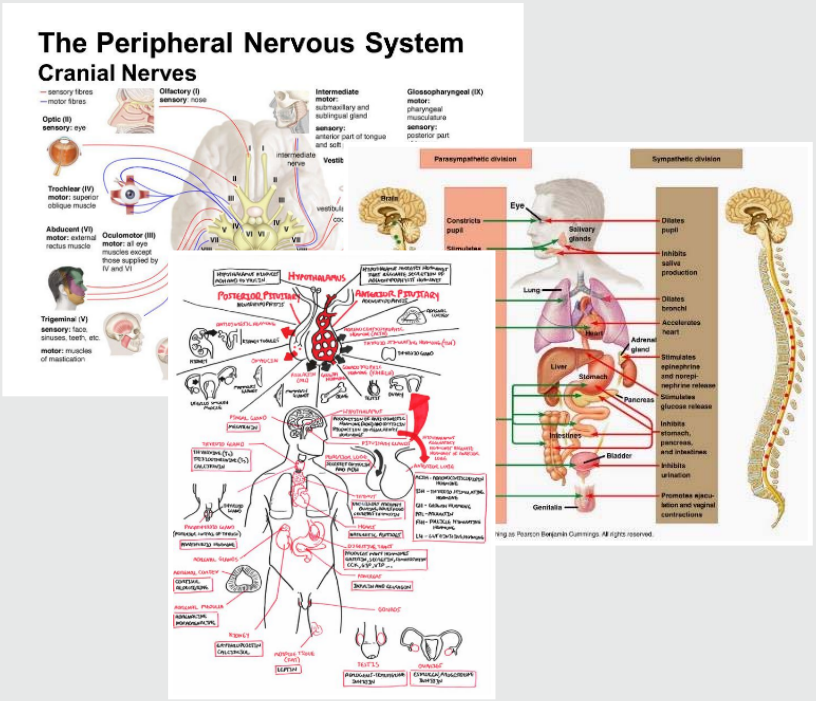
DIGITAL TWINS IN CHRONIC DISEASE
DEVICES & HUMANS

PHYSIOLOGY



HEALTHY

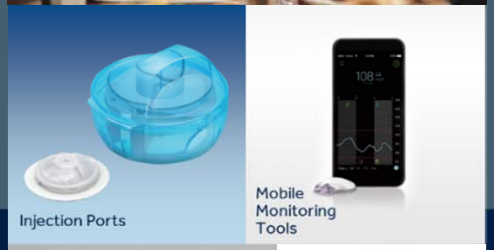
- complex milieu of overlapping control systems
- Multiple pathways influencing parameter of interest
- Coupled PDE's

CHRONIC DISEASE

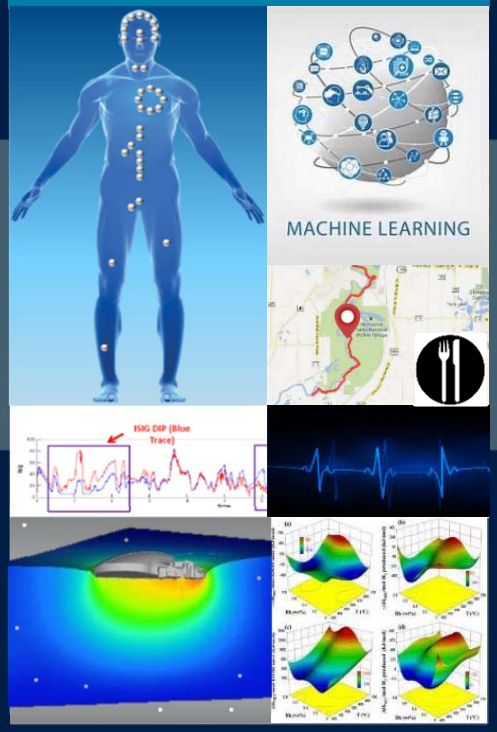
- Control systems are saturated
- Deviation from reference is clear
- Measurements well defined
- Axes of intervention well defined
- Coupled ODE's

DIGITAL TWINS IN CHRONIC DISEASE
SENSOR ENABLED DEVICES & HUMANS

PHYSICAL PRODUCTS IN THE REAL WORLD



VIRTUAL PRODUCTS AND LIGHT WEIGHT MODELS



ACTIONABLE PREDICTIONS

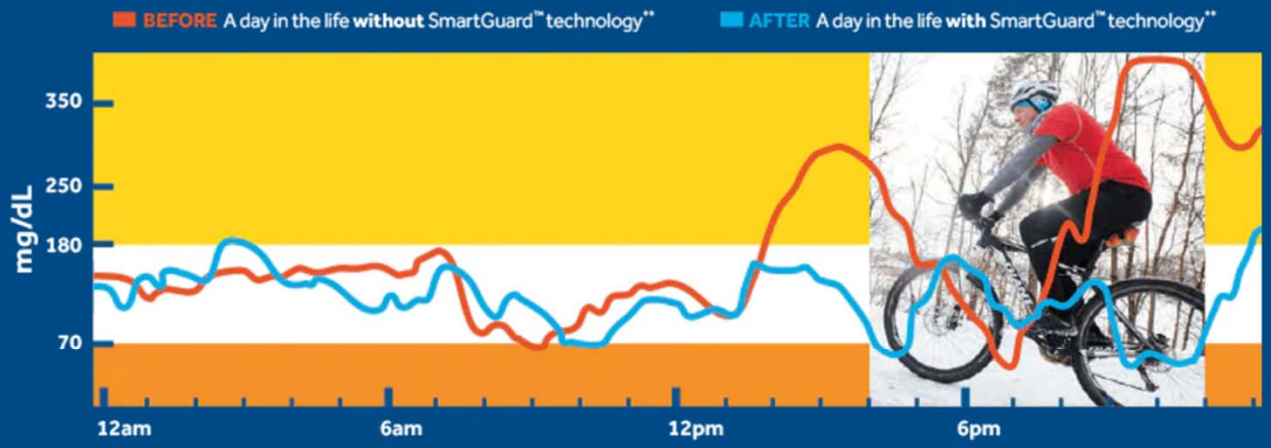
EMERGENCY PROTOCOL

WARNING PROTOCOL

SYSTEMS NORMAL

DIGITAL TWINS IN CHRONIC DISEASE
CLOSED LOOP GLUCOSE MANAGEMENT SYSTEM

- Algorithm adapts to individual patient's glucose metabolism
- Automatically adjusts basal (background) insulin every five minutes based on CGM readings
- Patient administers bolus for meals
- Algorithm is resistant to over or underestimation of carb consumption
- Stops insulin up to 30 minutes before reaching preset low limits



JOHN'S A1C.

BEFORE	AFTER
8.1	6.1

**Representative of actual patient Carelink™ data. Individual results may vary.

HELPS IMPROVE TIME IN RANGE.

With SmartGuard™ technology, John's glucose levels are automatically$^{\Delta}$ adjusted, so he is free to live life more in the moment.

- IN RANGE: 70-180 mg/dL
- HIGH: 180-400 mg/dL
- LOW: <70 mg/dL

DIGITAL TWINS IN HEALTHCARE
OPTIMIZING MANAGEMENT OF INDIVIDUAL HEALTH

HEALTHCARE

- Optimize health
- Predict and prevent adverse events
- Planned interventions
- Extend quality of life
- Extend life

"Clinical medicine seems to consist of a few things we know, a few things we think we know (but probably don't), and lots of things we don't know at all."

Naylor CD. "Grey zones of clinical practice: some limits to evidence-based medicine". Lancet. 1995;345:840-842

THANK YOU

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