AI-Driven Diabetes Care: dalla realtà clinica al paziente digitale

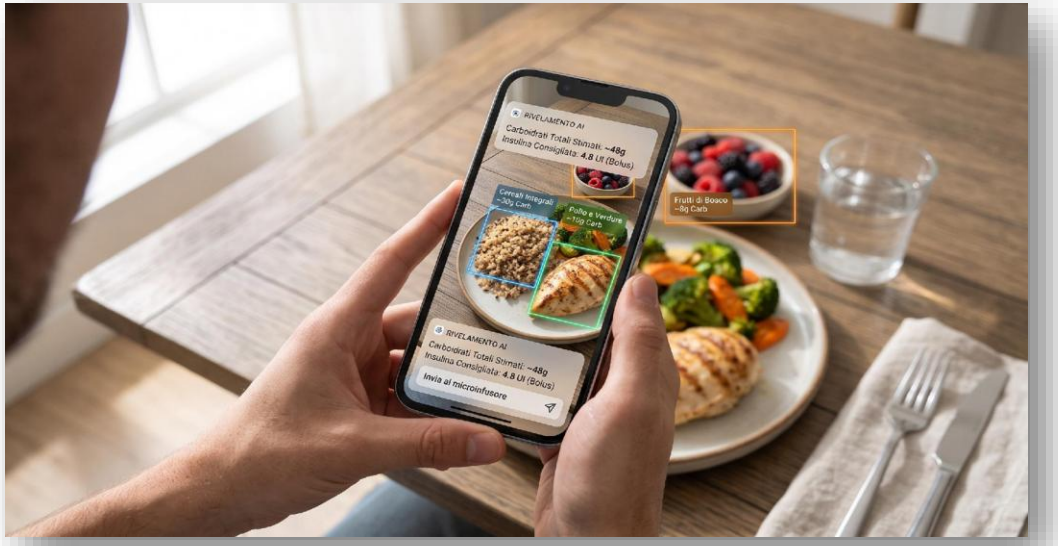
Micaela Morettini

Prof.ssa associata di Bioingegneria,
Dipartimento di Ingegneria dell'Informazione
Università Politecnica delle Marche (UnivPM)

DIABETE

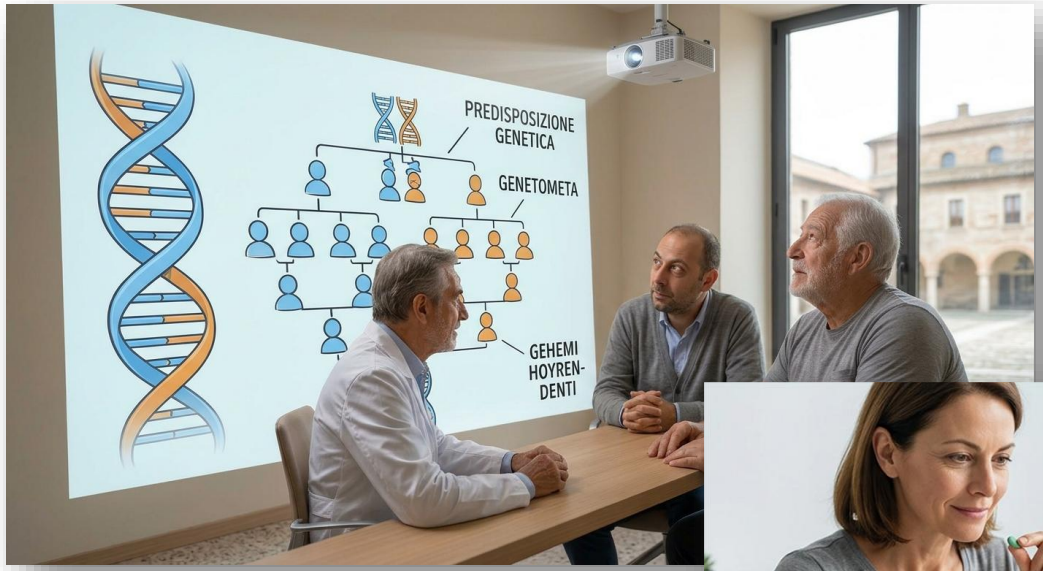





RIVELAMENTO AI
Carboidrati Totali Stimati: ~48g
Insulina Consigliata: 4.8 UI (Bolus)
Cereali Integrali ~20g Carb
Pollo e Verdure ~10g Carb
Frutti di Bosco ~8g Carb
RIVELAMENTO AI
Carboidrati Totali Stimati: ~48g
Insulina Consigliata: 4.8 UI (Bolus)
Invia al microinfusore


110 →

DIABETE


PREDISPOSIZIONE GENETICA
GENETOMETA
GEHEMI HOYREN-DENTI


REMEMBER: EAT BETTER.
COLA
ORANGE SODA
EXTRA CRUNCHY


Clinic
Glucose dashboard
98 mg/dL
Notifications
Oral Hypoglycemic Tablets


Metformina 500mg (T2D)
T2D - LUIGI R.
ANCONA - MEDICO: DR. B. ROSSI


PESO CORPOREO
95 kg
78 kg
MESI DI ATTIVITÀ FISICA
INSULINO-RESISTENZA
165 bpm
average during workouts
FREQUENZA CARDIACA
MESI DI ATTIVITÀ FISICA
CONSISTENZA DELL'ESERCIZIO
85% consistent, 5 days/week
T2D

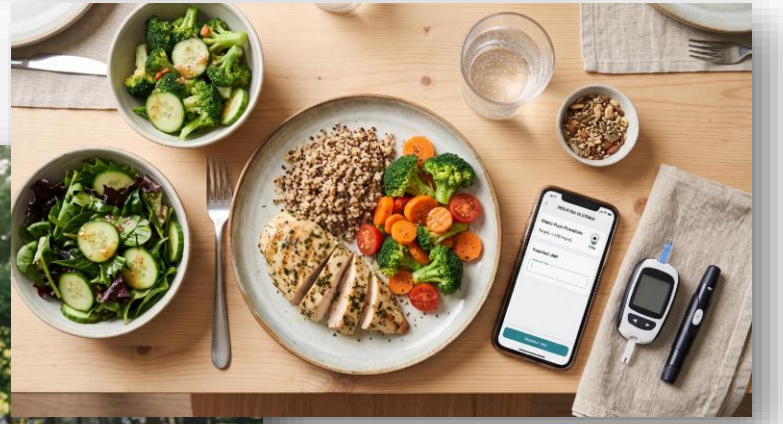
DIABETE











Il paziente digitale

Paziente



CGM e microinfusore



Wearable: ECG, EDA, temperatura



Pasti ed esercizio



Dati clinici e di laboratorio

Gemello digitale

Black box

Modelli data-driven / Machine Learning

White box

Modelli meccanicistici Fisiologia

Supporto alla decisione

- Simulazione di scenari what-if
- Predizioni e allarmi
- Test di terapie senza rischio
- **Clinico e paziente**

feedback: nuovi dati, nuove decisioni

I dati disponibili

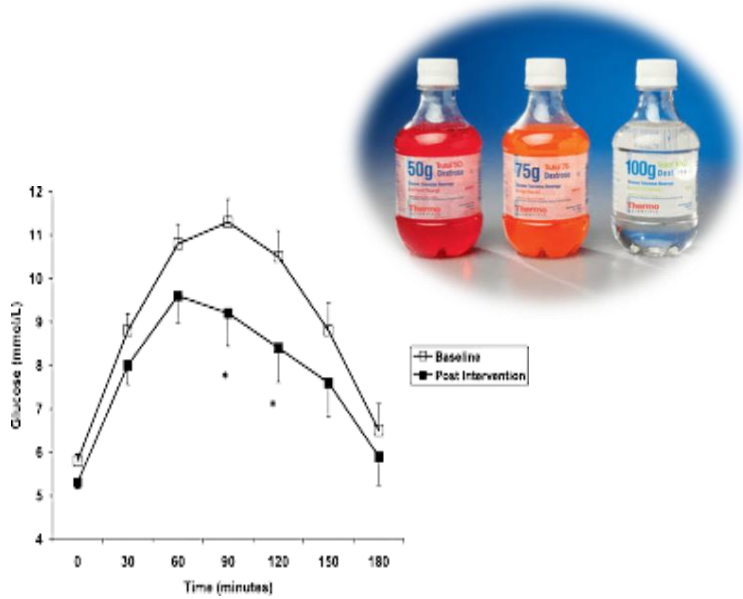
Tre famiglie di dati descrivono il paziente:



CGM



Werable device



Glucose tolerance test data

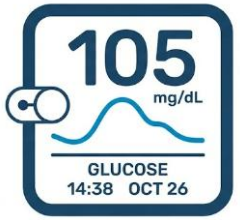
I dati disponibili



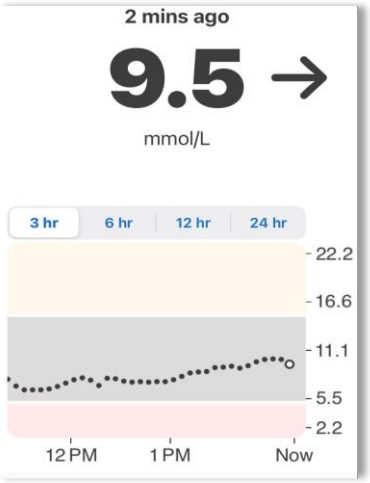
CGM

288

misure CGM al giorno
(una ogni 5 minuti)



Direzione e **velocità** della variazione glicemica



Metriche di stabilità:
Time in Range (TIR),
variabilità glicemica (CV)
e stime di HbA1c



I dati disponibili

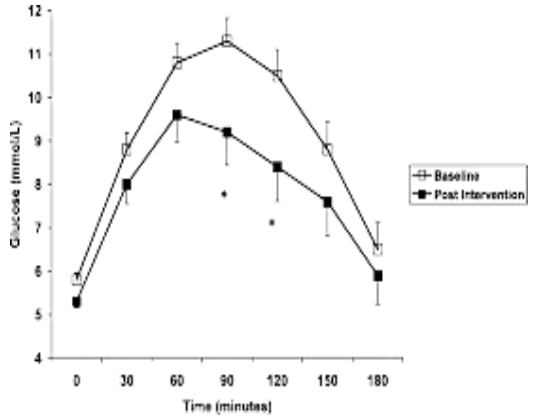
Tre famiglie di dati descrivono il paziente:



CGM



Werable device



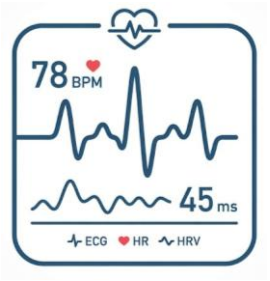
Glucose tolerance test data

I dati disponibili



Werable device

ECG, frequenza cardiaca a riposo, variabilità della frequenza cardiaca



Attività fisica e movimento
Conteggio dei passi, minuti di esercizio attivo, consumo calorico



Temperatura cutanea, attività elettrodermica, monitoraggio sulla qualità/durata del sonno



I dati disponibili

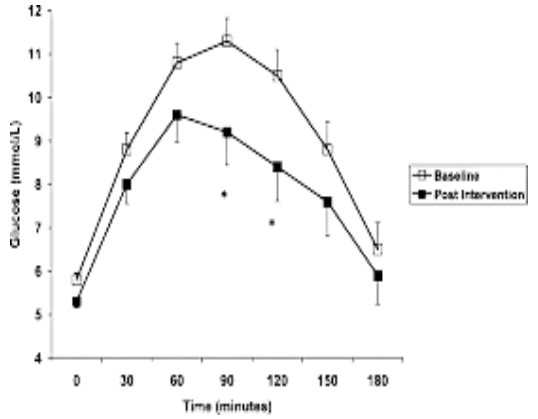
Tre famiglie di dati descrivono il paziente:



CGM

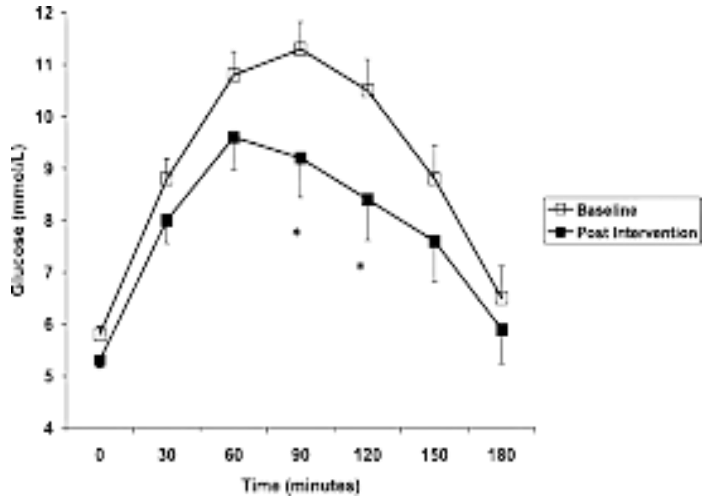


Werable device



Glucose tolerance test data

I dati disponibili



Glucose tolerance test data

Massimo 30 campioni

Da 2 a 6 ore di test

Indici di tolleranza e resistenza: Valutazione della tolleranza glucidica, picco glicemico massimo e tempi di ritorno ai valori basali

I dati disponibili

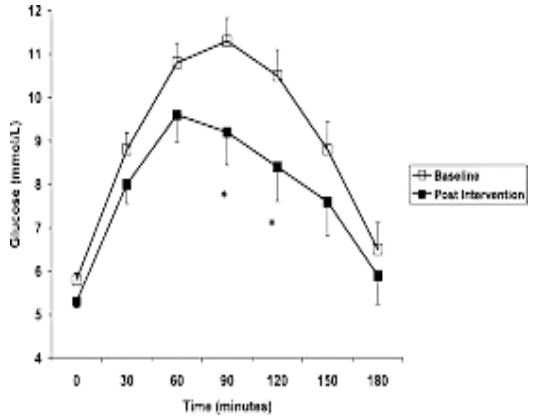
Tre famiglie di dati descrivono il paziente:



CGM



Werable device



Glucose tolerance test data

Scarsità di dati

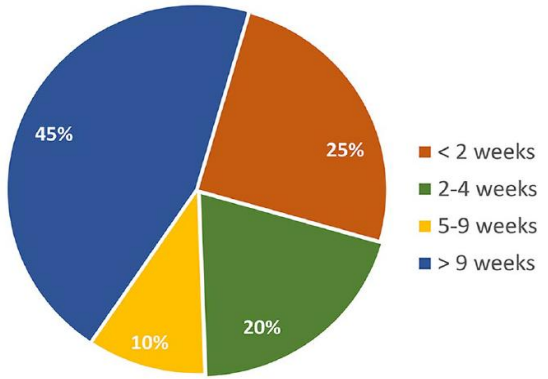


Review Article

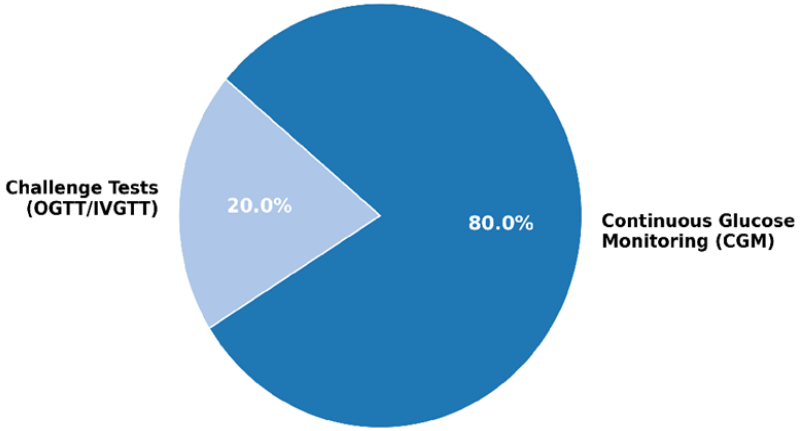
Availability of Open Dynamic Glycemic Data in the Field of Diabetes Research: A Scoping Review

Libera Lucia Del Giudice, MSc[1], Agnese Piersanti, PhD[2], Christian Göbl, MD, PhD, MSc[3], Laura Burattini, PhD[1], Andrea Tura, PhD[2], and Micaela Morettini, PhD[1]

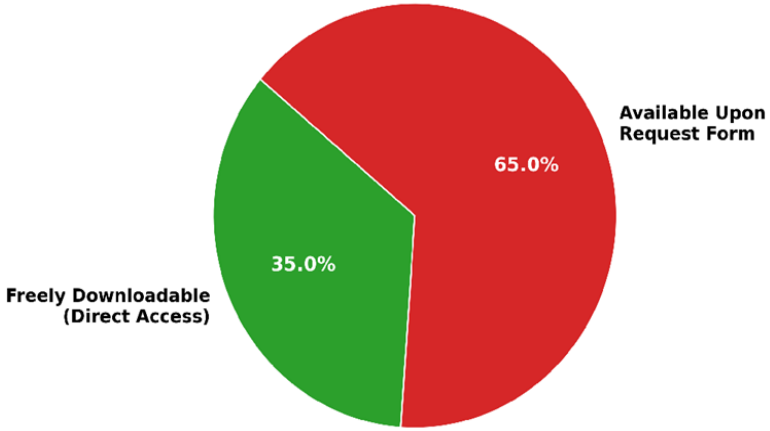
Length of CGM tracing



Distribution of Retrieved Dynamic Glycemic Datasets (Total = 25)



Accessibility of CGM Datasets (Total = 20) *Note: Mostly T1D, scarce for T2D



Coorti piccole

Studi clinici con decine o centinaia di soggetti

Eventi rari

Ipoglicemie ed esiti avversi: classi molto sbilanciate

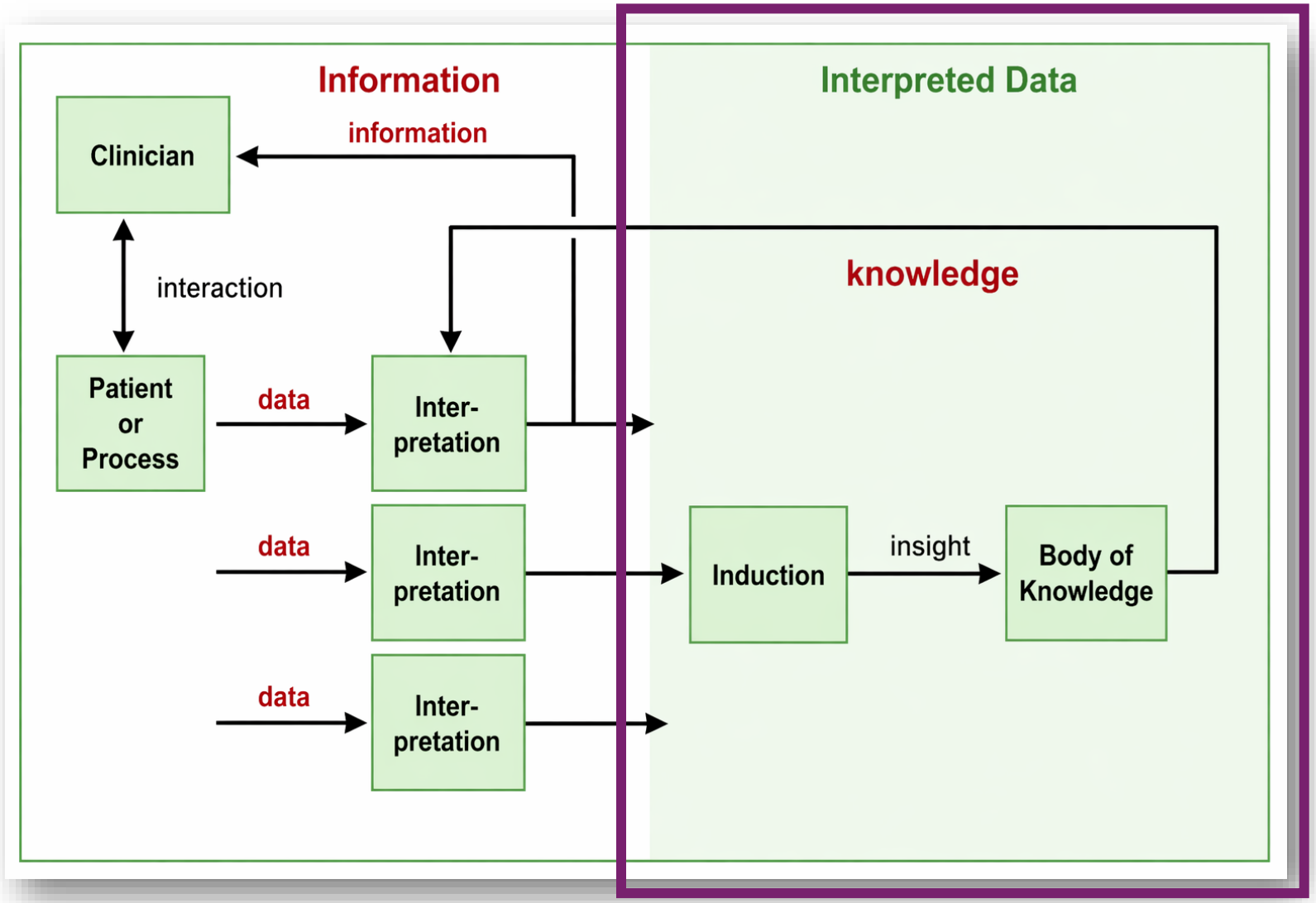
Eterogeneità

Dispositivi, protocolli e popolazioni diverse

Privacy e invasività

Dati sensibili e procedure onerose da ripetere (OGTT, clamp)

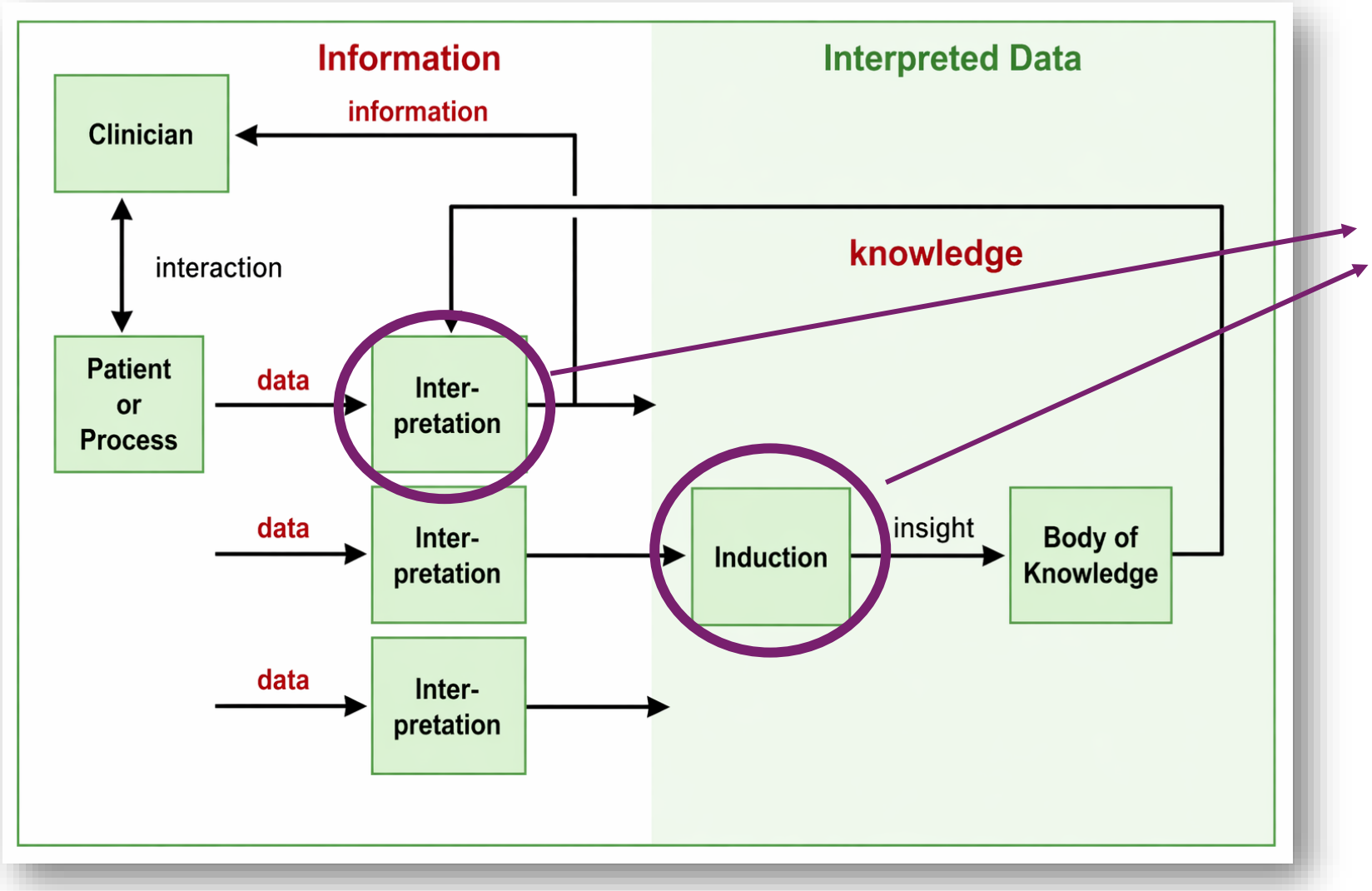
Dal dato alla conoscenza



L'informazione derivante dall'interpretazione di numerosi dati, insieme al ragionamento induttivo, genera ed accresce la CONOSCENZA.

Van Bemmel et al., Handbook of Medical Informatics, 1997

Dove entrano i modelli?



FORMULAZIONE DI MODELLI

Van Bemmel et al., Handbook of Medical Informatics, 1997

Lo spettro dei modelli in silico



Black box

Modelli data-driven / Machine Learning

White box

Modelli meccanicistici Fisiologia

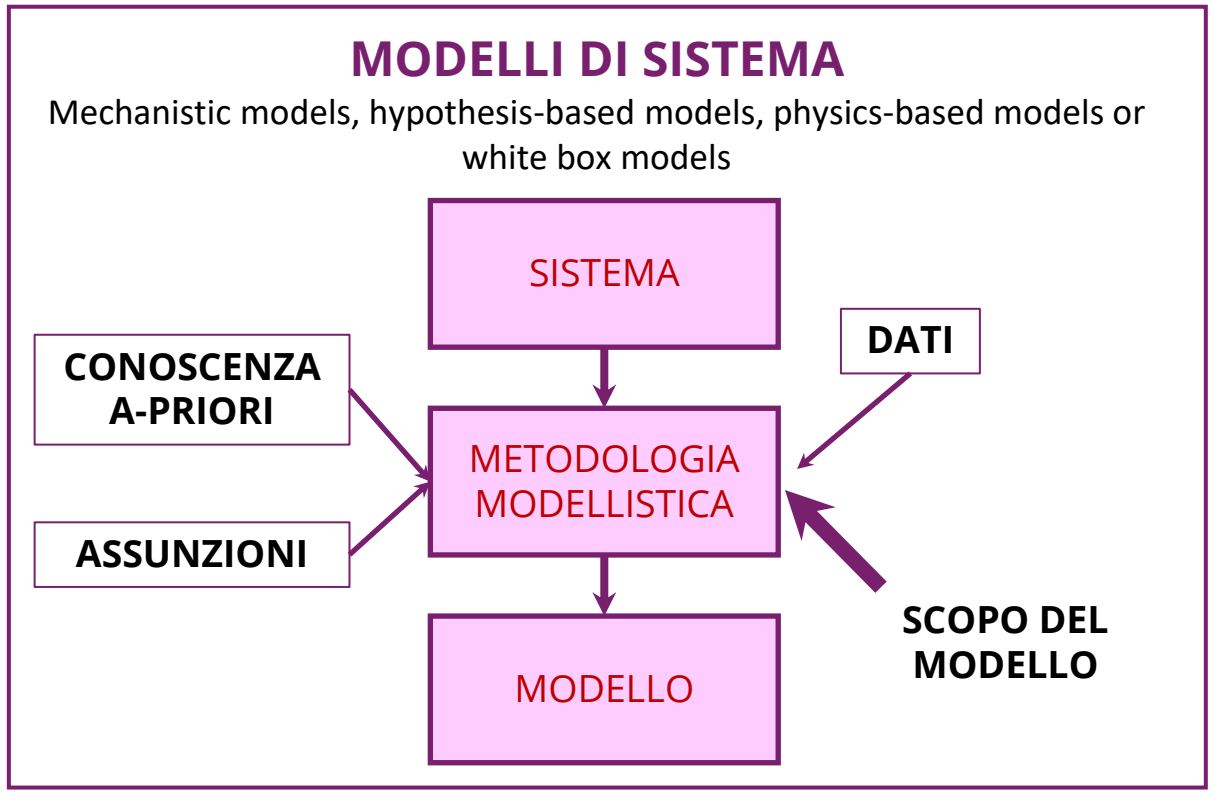
AI Task Force of the Research & Technology Working Group of the Avicenna Alliance. The role of artificial intelligence within in silico medicine

Modellazione matematica… tradizionalmente definita

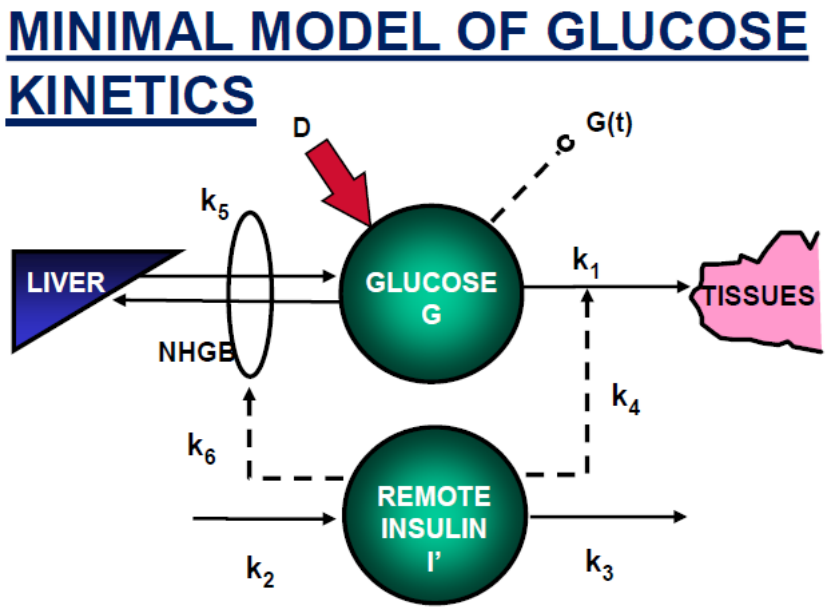
"Mathematical modeling is an attempt to describe some part of the real world in mathematical terms. It is an endeavor as old as antiquity but as modern as tomorrow's newspaper. It has led to some good mathematical models and some bad ones, which are best forgotten. Sometimes mathematical models have been welcomed with great enthusiasm—even when their value was uncertain or negligible; other times good mathematical models have been greeted with indifference, hostility, or ridicule. Mathematical models have been built in the physical, biological, and social sciences. The building blocks for these models have been taken from calculus, algebra, geometry, and nearly every other field within mathematics."

W.J Meyer. Concepts of mathematical modeling. McGraw-Hill, 1984

Modelli in silico: differenti tipologie



Il modello minimo di Bergman

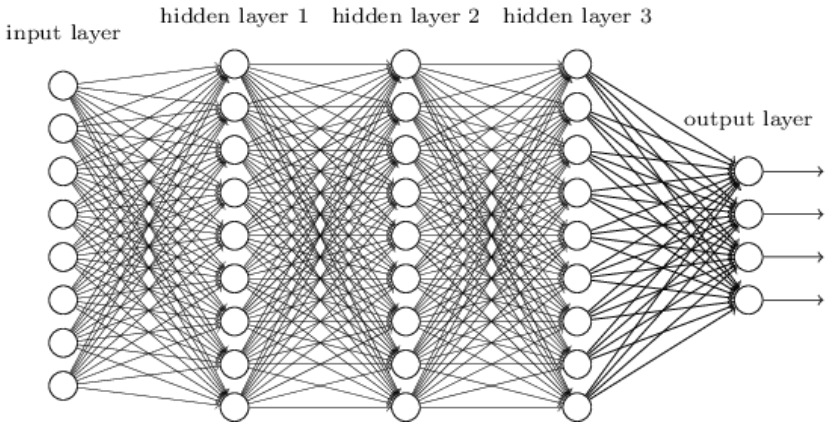


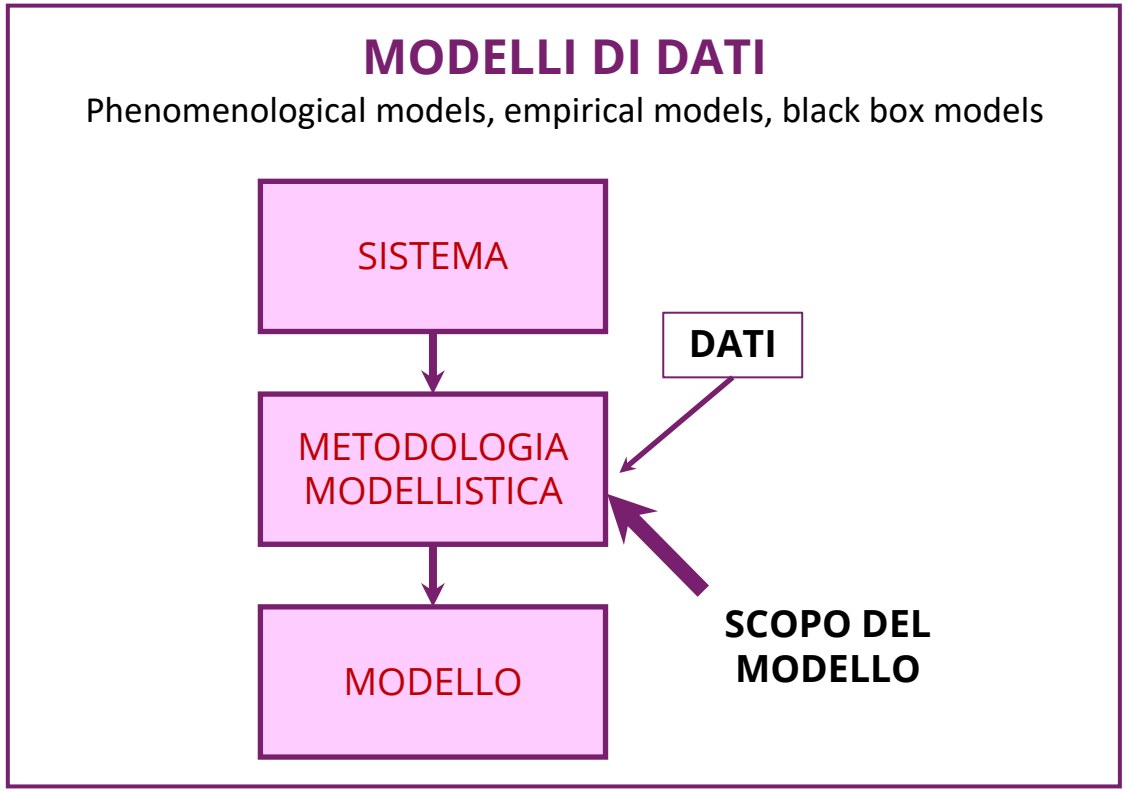
"in silico models that are based on prior knowledge on cause-and-effect relationships"

Ewart R. Carson, Claudio Cobelli. Modelling Methodology for Physiology and Medicine. Academic Press, 2001
AI Task Force of the Research & Technology Working Group of the Avicenna Alliance. The role of artificial intelligence within in silico medicine

Modelli in silico: differenti tipologie

Black-box Approach

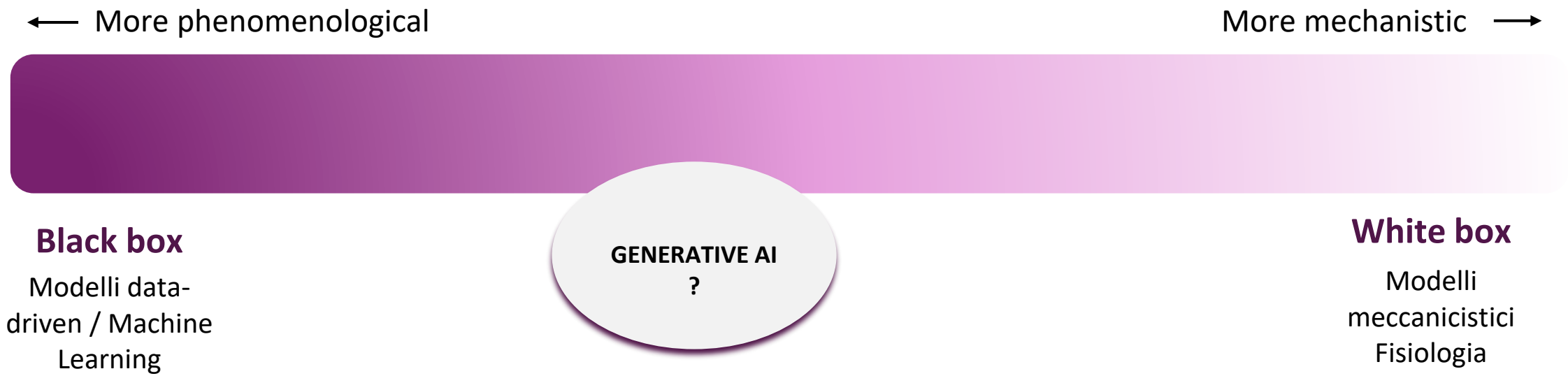




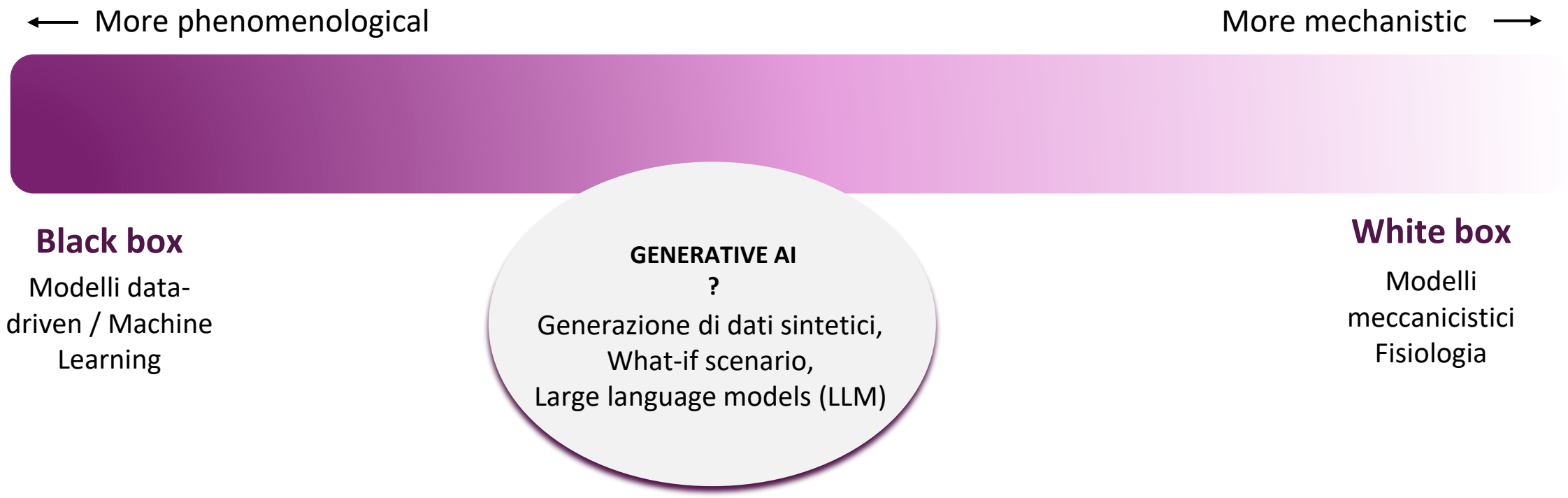
"in silico models that develop a predictor automatically for the data without making any causal assumptions"

Ewart R. Carson, Claudio Cobelli. Modelling Methodology for Physiology and Medicine. Academic Press, 2001
AI Task Force of the Research & Technology Working Group of the Avicenna Alliance. The role of artificial intelligence within in silico medicine

Lo spettro dei modelli in silico



Lo spettro dei modelli in silico



Il paziente digitale ibrido

Paziente

CGM e microinfusore

Wearable: ECG, EDA, temperatura

Pasti ed esercizio

Dati clinici e di laboratorio

Gemello digitale

Black box
Modelli data-driven / Machine Learning

White box
Modelli meccanicistici Fisiologia

Supporto alla decisione

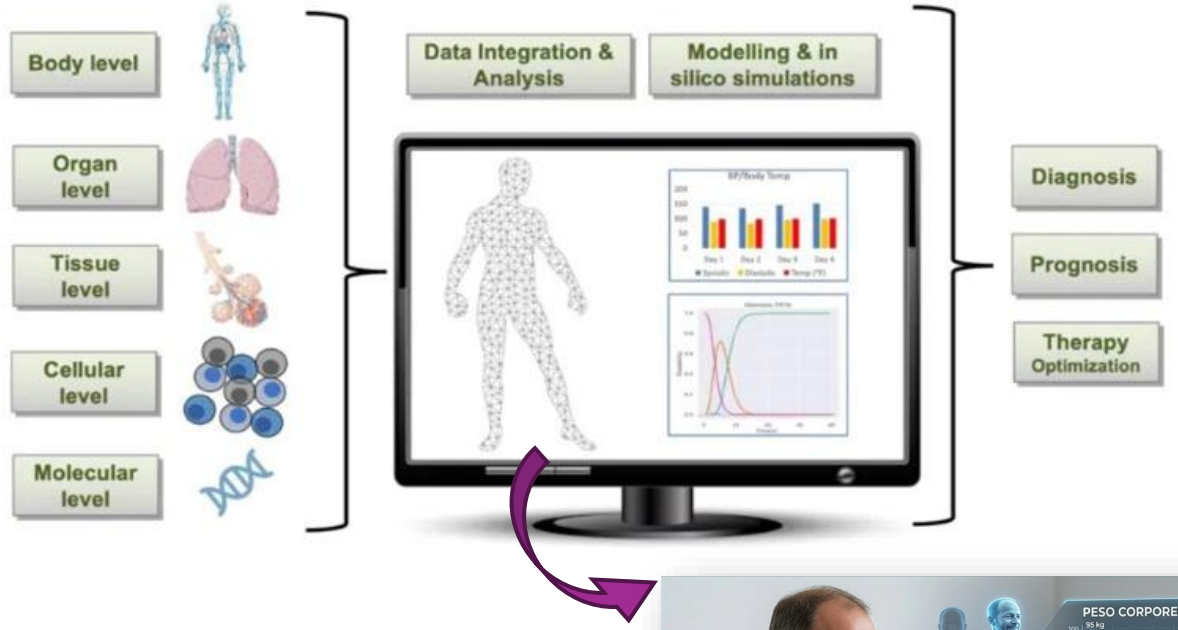
- Simulazione di scenari what-if
- Predizioni e allarmi
- Test di terapie senza rischio
- **Clinico e paziente**

feedback: nuovi dati, nuove decisioni

Gemello digitale

A DIGITAL TWIN is “a virtual copy of a system able to interact with the physical system in a bi-directional way”

Dati biologici multiscala | Gemello digitale | Assistenza personalizzata





Perché l’AI deve stare vicino al paziente

Paziente


CGM e microinfusore


Wearable: ECG, EDA, temperatura


Pasti ed esercizio


Dati clinici e di laboratorio

Gemello digitale

Black box
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Supporto alla decisione

- Simulazione di scenari what-if
- Predizioni e allarmi
- Test di terapie senza rischio
- **Clinico e paziente**

Edge AI

feature + ML leggero + modelli matematici

smartphone · app · microinfusore

Cloud e clinico

twinning, validazione

Modelli ML leggeri: poche feature, struttura semplice, interpretabili. Una volta validati, possono girare sul dispositivo e vengono aggiornati dopo la procedura di twinning.

AI on the edge: Feature extraction





Diabetes Technology & Therapeutics > Vol. 25, No. 1

Review Article | NO ACCESS | Published Online: 27 December 2022

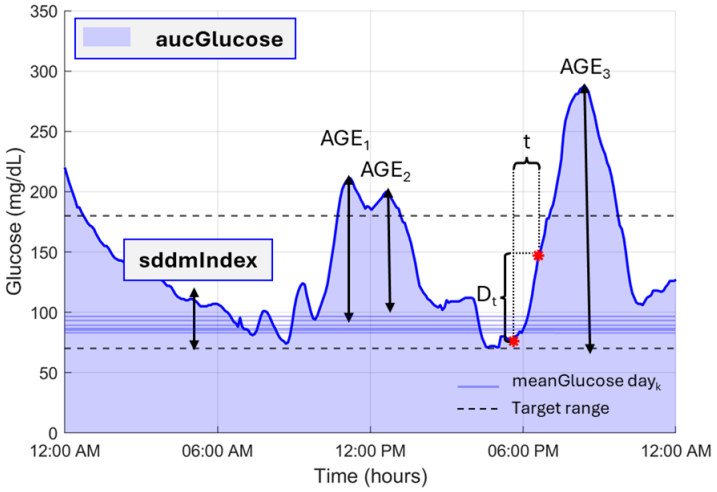
Software Packages and Tools for the Analysis of Continuous Glucose Monitoring Data

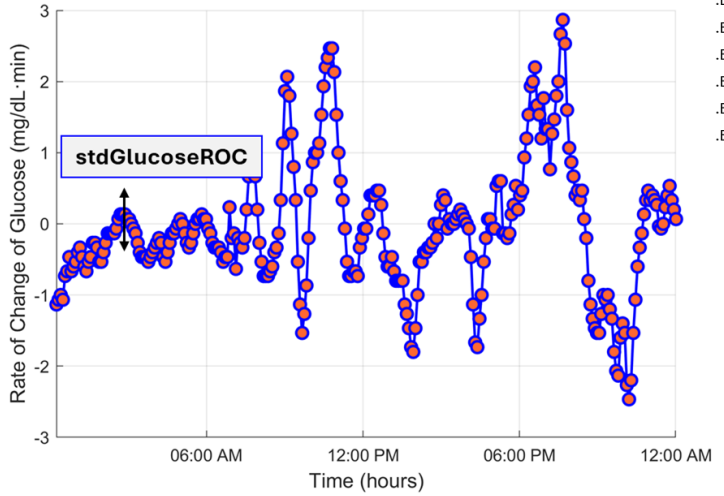
Authors: Agnese Piersanti, Francesco Giurato, Christian Göbl, Laura Burattini, Andrea Tura, and Micaela Morettini AUTHORS INFO & AFFILIATIONS

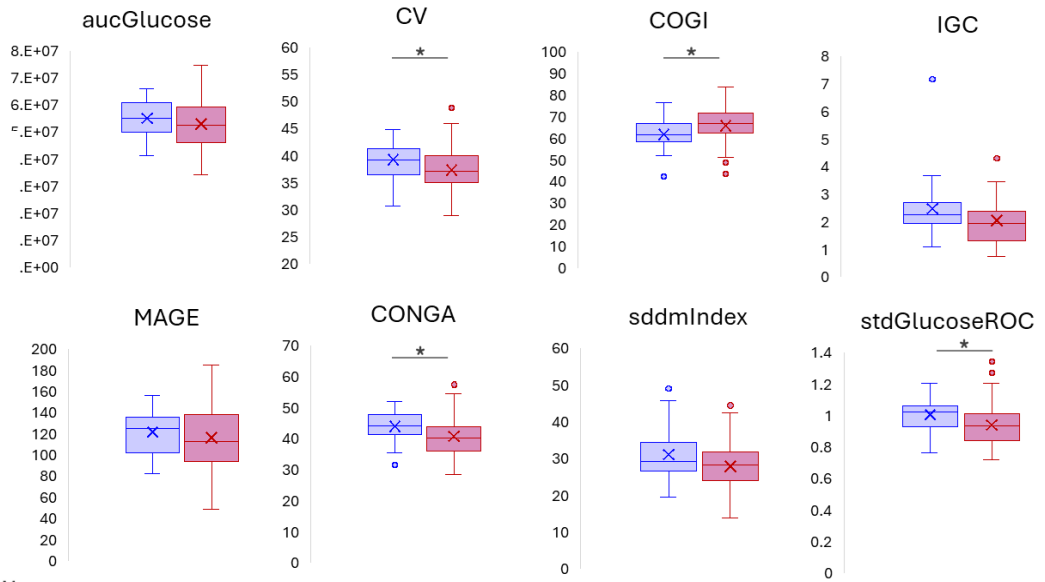
Publication: Diabetes Technology & Therapeutics • https://doi.org/10.1089/dia.2022.0237

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$$\mathbf{MAGE} = \sum_{i=1}^{n} \mathrm{AGE}_i$$







MAGE : amplitude of glycemic excursion

CGM in gravidanza: lo studio GRACE



Glycaemic control and pregnancy outcomes with real-time continuous glucose monitoring in gestational diabetes (GRACE): an open-label, multicentre, multinational, randomised controlled trial

Tina Linder, Iris Dressler-Steinbach, Silke Wegener, Karen Schellong, Saskia Schmidt, Daniel Eppel, Cécile Monod, Florian Heinzl, Katharina Redling, Bettina Winzeler, Beatrice Mosimann, Friederike Weschenfelder, Tanja Groten, Martina Mittlböck, Johan Jendle, Wolfgang Henrich, Micaela Morettini, Latife Bozkurt, Andrea Tura, Christian Göbl, the GRACE study collaborative group

Summary

Background Data regarding the impact of real-time continuous glucose monitoring (rt-CGM) on reducing adverse pregnancy outcomes in women with gestational diabetes are contradictory. We aimed to assess differences in the proportion of large-for-gestational-age (LGA) newborns between women using rt-CGM versus self-monitoring of blood glucose (SMBG).

Lancet Diabetes Endocrinol 2025
Published Online November 24, 2025
https://doi.org/10.1016/S2213-8587(25)00288-8
See Online/Comment

In collaboration with:

MEDICAL UNIVERSITY OF VIENNA

Consiglio Nazionale delle Ricerche

Related project:
GRACE study. PI: Prof. Christian Gobl

AI on the edge: predizione dell'ipoglicemia

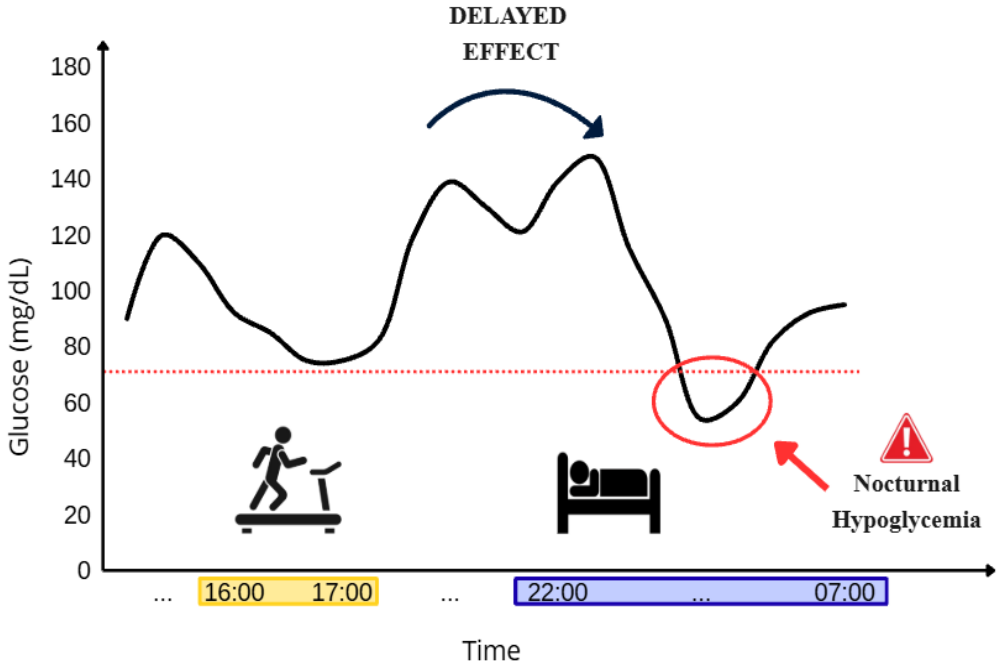




- Indotta da esercizio fisico in pazienti con T1D
- Ipoglicemia notturna
- Ipoglicemia durante emodialisi

↓

Modelli interpretabili stimano il rischio di ipoglicemia e alimentano un sistema di supporto alla decisione clinica



ELSEVIER

Biomedical Signal Processing and Control

Volume 102, April 2025, 107319



Research article • Full text access Get rights and content ↗

Assessing hypoglycemia risk during hemodialysis using an explainable machine learning approach based on continuous glucose monitoring metrics

Agnese Piersanti [a], Micaela Morettini [b], Stefania Cristino [c], Libera Lucia Del Giudice [b], Laura Burattini [b], Giovanni Mosconi [c], Christian S. Göbl [d e], Emanuele Mambelli [f], Andrea Tura [a] Show more

Open Access Feature Paper Article

Prediction of Nocturnal Hypoglycemia Following Exercise in Type 1 Diabetes Using Temporally Structured CGM-Derived Digital Biomarkers

by Agnese Piersanti [1,†], Gaia Maria Manes [1,†], Libera Lucia Del Giudice [1], Laura Burattini [1], Christian Göbl [2], Andrea Tura [3] and Micaela Morettini [1,*]

Complicanze croniche dal CGM

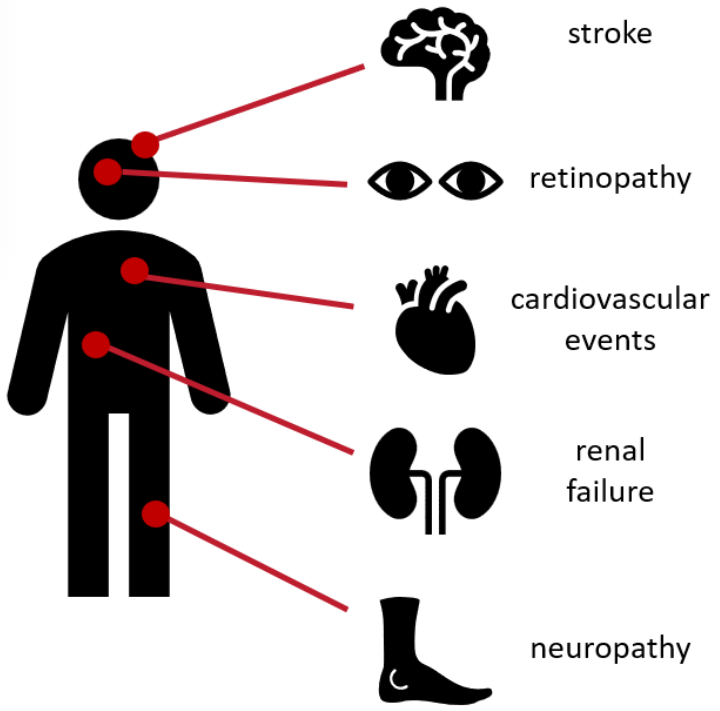


Identifying Hypothyroidism as Complication of Type 1 Diabetes from Continuous Glucose Monitoring Data

Agnese Piersanti, *Member, IEEE,* Agnese Callegari, Libera L. Del Giudice, *Student Member, IEEE,* Christian Göbl, Laura Burattini, *Member, IEEE,* Andrea Tura and Micaela Morettini, *Member, IEEE*

Diabetic Retinopathy Detection: A Machine-Learning Approach Based on Continuous Glucose Monitoring Metrics

Agnese Piersanti[1], Benedetta Salvatori[2], Piera D' Avino[1], Laura Burattini[1], Christian Göbl[3,4], Andrea Tura[2], and Micaela Morettini[1]



Le metriche CGM diventano biomarcatori per individuare precocemente retinopatia diabetica e ipotiroidismo

Fenotipi del diabete gestazionale

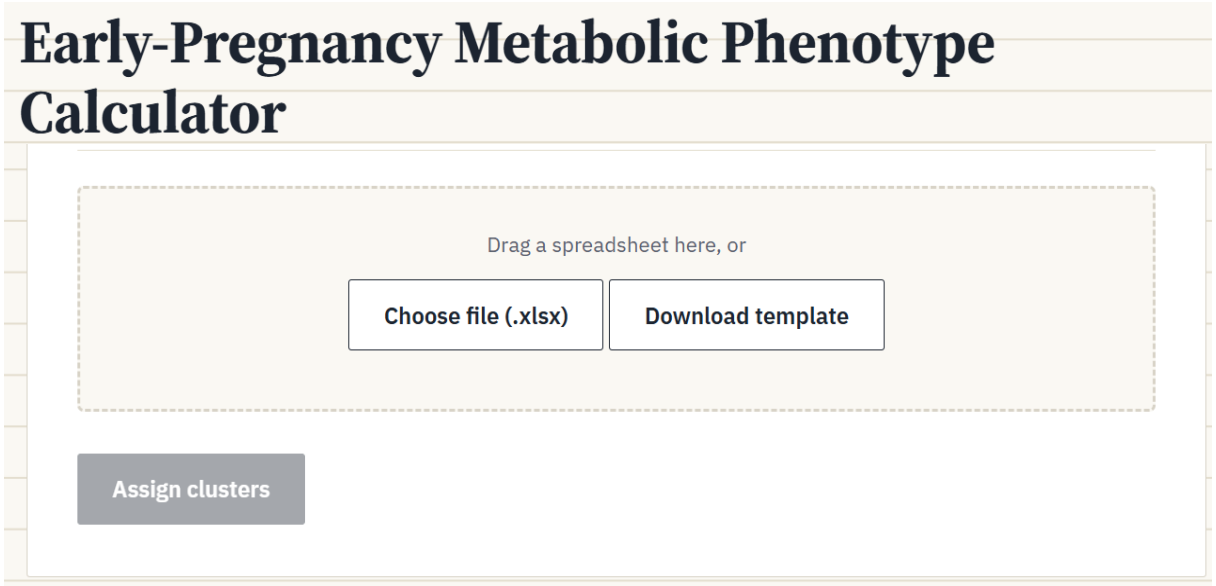


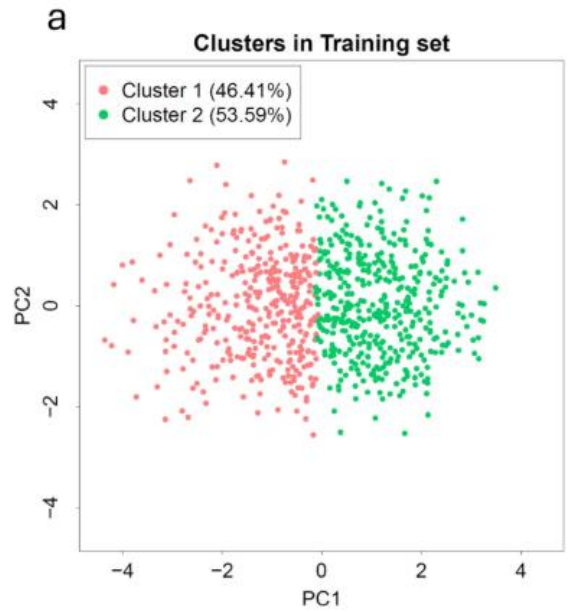
Diabetologia (2024) 67:1552–1566
https://doi.org/10.1007/s00125-024-06184-7

ARTICLE

Identification and validation of gestational diabetes subgroups by data-driven cluster analysis

Benedetta Salvatori[1] · Silke Wegener[2] · Grammata Kotzaeridi[3] · Annika Herding[3] · Florian Eppel[3] · Iris Dressler-Steinbach[2] · Wolfgang Henrich[2] · Agnese Piersanti[4] · Micaela Morettini[4] · Andrea Tura[1] · Christian S. Göbl[3,5]





CL1 women had higher rates of the indicated **adverse outcomes**

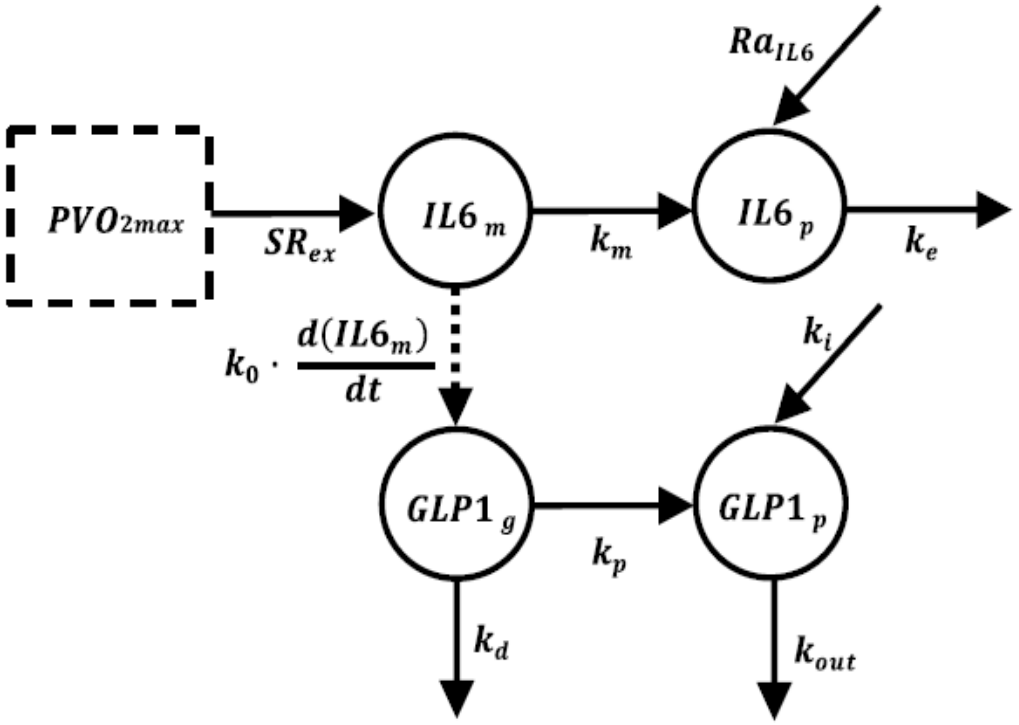
In collaboration with:

MEDICAL UNIVERSITY OF VIENNA

Consiglio Nazionale delle **Ricerche**

Related project:
EFSD/Lilly European Diabetes Research Programme
Phenotypes of Gestational Diabetes Mellitus and their heterogeneity in insulin action and beta-cell function.
PI: Prof. Christian Gobl

Immunometabolismo ed esercizio



PLOS ONE

RESEARCH ARTICLE

A system model of the effects of exercise on plasma Interleukin-6 dynamics in healthy individuals: Role of skeletal muscle and adipose tissue

Micaela Morettini[1,2]*, Maria Concetta Palumbo[2], Massimo Sacchetti[3], Filippo Castiglione[2], Claudia Mazza[4,5]

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

Glucagon-like peptide-1 and interleukin-6 interaction in response to physical exercise: An in-silico model in the framework of immunometabolism

Micaela Morettini [a,*], Maria Concetta Palumbo [b], Alessandro Bottiglione [a], Andrea Danieli [a], Simone Del Giudice [a], Laura Burattini [a], Andrea Tura [c]

Computers in Biology and Medicine 163 (2023) 107158

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

A computational model of the effects of macronutrients absorption and physical exercise on hormonal regulation and metabolic homeostasis

Maria Concetta Palumbo [a,*], Albert A. de Graaf [b], Micaela Morettini [c], Paolo Tieri [a], Shaji Krishnan [d], Filippo Castiglione [a,1]

In collaboration with:

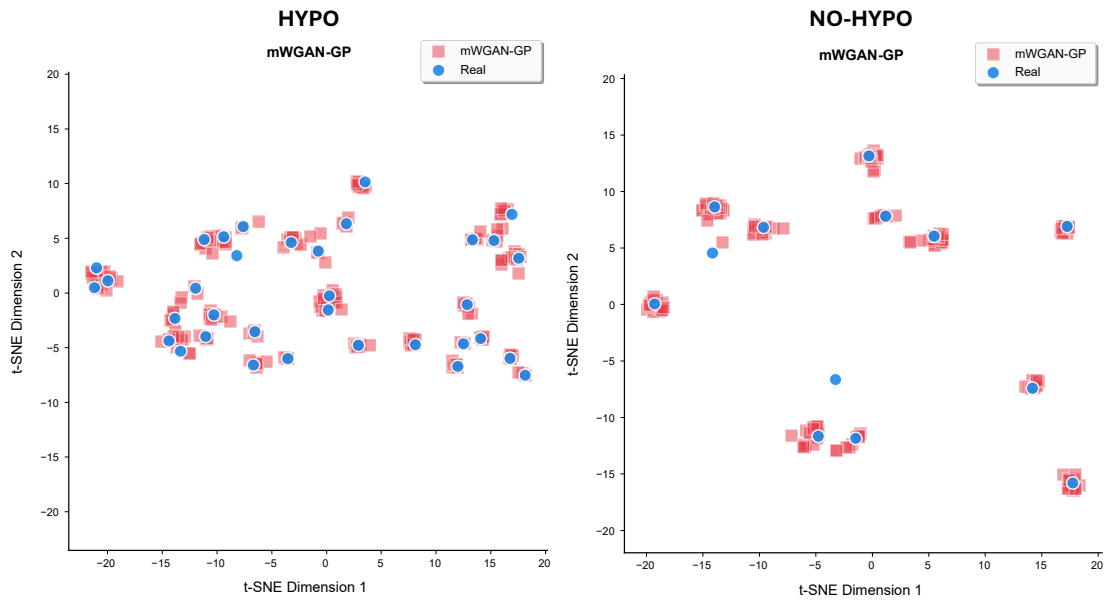
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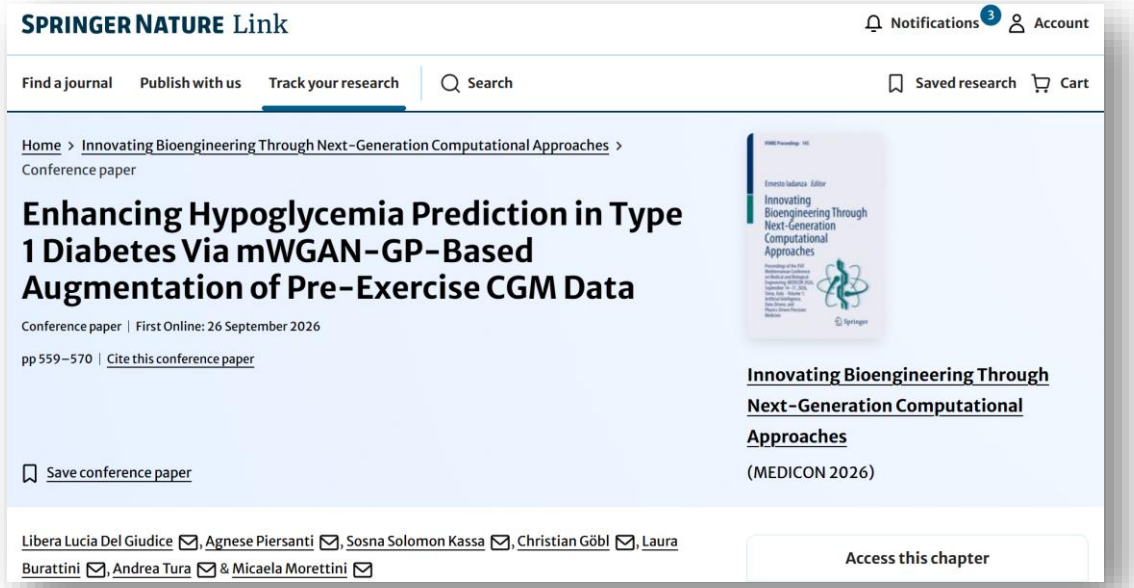
Università degli Studi di Roma "Foro Italico" 1928

Related project:
MISSION-T2D Multiscale Immune System Simulator for the ONset of Type 2 Diabetes integrating genetic, metabolic and nutritional data.

Dati sintetici con IA generativa: mWGAN






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Conference paper

Enhancing Hypoglycemia Prediction in Type 1 Diabetes Via mWGAN-GP-Based Augmentation of Pre-Exercise CGM Data

Conference paper | First Online: 26 September 2026

pp 559–570 | Cite this conference paper

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Innovating Bioengineering Through Next-Generation Computational Approaches

(MEDICON 2026)

Libera Lucia Del Giudice, Agnese Piersanti, Sosna Solomon Kassa, Christian Göbl, Laura Burattini, Andrea Tura & Micaela Morettini

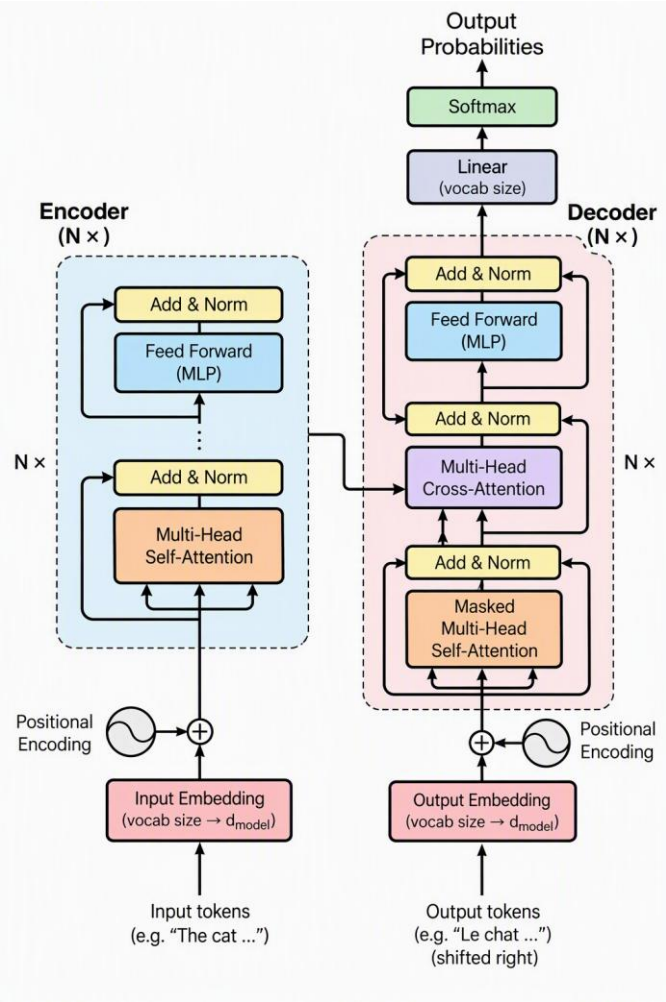
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Bi-LSTM Performance Metrics for Test set

Metrics	Custom-made augmented data	mWGAN-GP augmented data
Area Under the ROC Curve (AUC)	88.6%	90.9%
Classification Accuracy (CA)	66.7%	73.3%
Precision (PR)	87.5%	88.9%
Sensitivity (SE)	63.6%	72.7%
Specificity (SP)	75.0%	75.0%
F1-score (F1)	73.7%	80.0%

Transformer: “what if” scenario



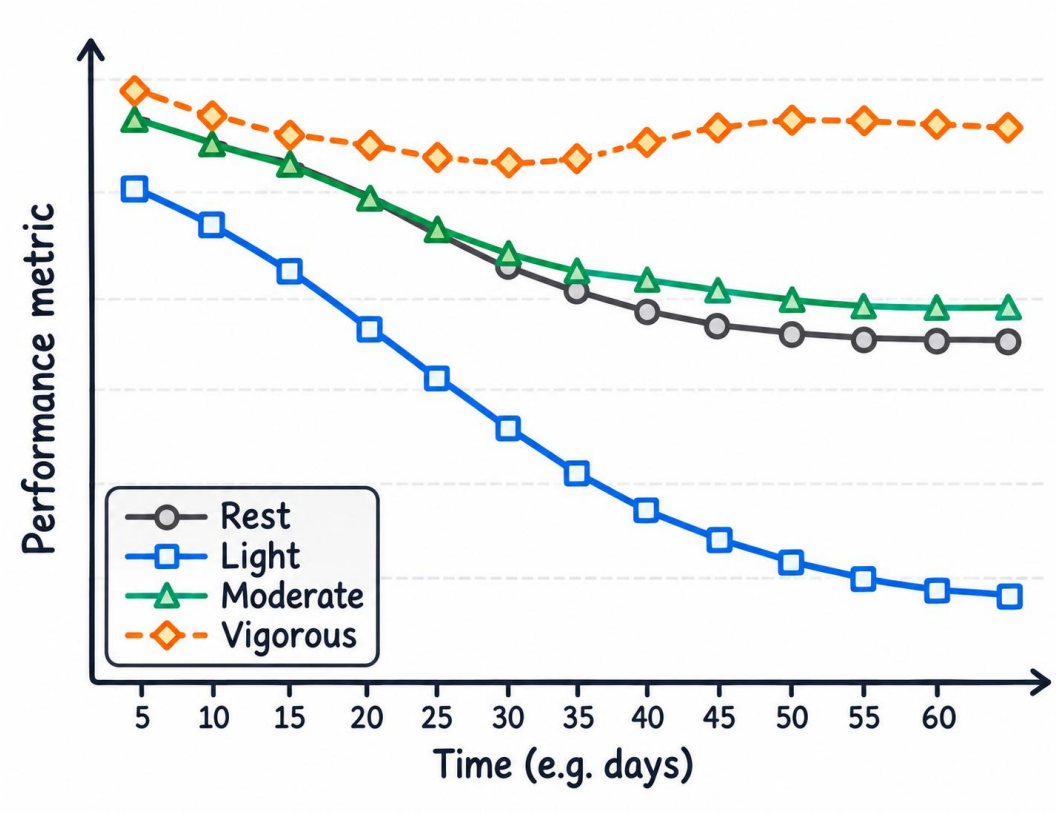












Valuta se le variazioni nell’intensità dell’esercizio fisico possano modificare la risposta glicemica prevista verso un profilo glicemico più salutare

Take home message

1. **Il diabete è un problema ingegneristico**
   Dati continui, forte variabilità individuale, decisioni ogni giorno

2. **L’AI utile in clinica è interpretabile e validata**
   Non il modello più complesso, ma quello che il clinico può capire e usare

3. **Il futuro è ibrido**
   Modelli fisiologici più apprendimento dai dati: il paziente digitale

Diabetes Lab –
Department of Information Engineering

People

- Micaela Morettini, *Associate professor*
- Agnese Piersanti, *Post-doc fellow*
- Libera Del Giudice, *PhD student*

Teaching activities

- Medical informatics
- Models and control of biological systems

Biomedical Eng. Ms students (2026)

- Lucia Ricci
- Cathy Matchowong
  (in collaboration with AST Pesaro-Urbino)
- Gaia Maria Manes
- Sosna Solomon Kassa







Grazie per l'attenzione. Domande?