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Digital Transformation of Medical Diagnostics: Biomarker Integration, Intelligent Endoscopy, and Data-Guided Surgery

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ABSTRACT

Today's medicine is undergoing a revolution driven by digital transformation, which promotes more accurate diagnoses, personalized treatments, and data-driven decision-making. This article explores three essential components of this evolution: digital biomarkers, smart endoscopy, and data-guided surgery. Through a systematic review of recent literature, we analyze how these technologies converge to optimize medical diagnosis, reduce clinical variability, and improve health outcomes. The advances made, the pending challenges and the ethical implications of the use of artificial intelligence and big data in medicine are highlighted.

Keywords: Digital transformation, biomarkers, smart endoscopy, data-guided surgery, artificial intelligence, medical diagnostics, big data.

INTRODUCTION

The digital transformation of the health sector has ushered in a new era in medicine, characterized by the integration of emerging technologies in the process of diagnosis, treatment, and clinical follow-up. This structural change is not limited to the digitization of records or the use of electronic devices, but encompasses a deeper revolution: the convergence of artificial intelligence (AI), big data, predictive analytics, biomedical sensors, and interconnected digital platforms. These advances have created new opportunities to optimize healthcare, improve diagnostic accuracy, and reduce operational times and costs (Razzak, Imran, & Xu, 2019; Miotto, Wang, Wang, Jiang & Dudley, 2021).

In particular, **digital biomarkers** represent a growing field, where physiological and behavioral parameters are recorded by wearable sensors and smart devices to anticipate or detect relevant clinical changes. These tools allow continuous, non-invasive monitoring based on real-time data, which favors personalized, predictive, and preventive medicine (Izmailova, Wagner, & Perakslis, 2020). Digital biomarkers hold particular promise in chronic diseases such as cancer, diabetes, and neurodegenerative disorders, where longitudinal follow-up of the patient is critical for timely intervention.

On the other hand, **smart endoscopy**, powered by AI algorithms and convolutional neural networks, has managed to revolutionize endoscopic diagnostic procedures, especially in the digestive tract. The ability of these systems to detect subtle lesions more accurately than the human eye has been validated in multiple multicenter clinical studies (Wu et al., 2022). In addition, AI in endoscopy has been shown to reduce interobserver variability and increase detection rates of adenomas and polyps in colonoscopies (Yamada et al., 2023), which may translate into a significant reduction in the incidence of colorectal cancer.

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Likewise, **data-guided surgery** emerges as a disruptive technology in the operating room. Thanks to the integration of three-dimensional medical images, intraoperative sensors, computational modeling, and augmented reality, surgeons can plan and execute interventions with an unprecedented degree of precision. These tools not only improve anatomical visualization, but also allow for safer and more informed decision-making, reducing surgical errors and improving postoperative outcomes (Hashimoto et al., 2022; Liew, Liu & Koh, 2022).

Despite their benefits, the adoption of these technologies presents significant challenges, such as interoperability between platforms, patient data protection, evolving regulatory frameworks, and the training of healthcare personnel. The ethical and safe integration of AI and automated systems into medical practice also continues to be debated in the recent literature (Meskó, Drobni, Bényei, Gergely & Győrffy, 2020).

Therefore, this article aims to analyze the synergistic integration of digital biomarkers, smart endoscopy, and data-guided surgery in medical diagnosis, evaluating their clinical impact, benefits, associated risks, and future projections, in the light of recent scientific evidence.

THEORETICAL FRAMEWORK

Digital transformation has redefined the traditional approach to medical diagnosis by integrating advanced technologies such as digital biomarkers, smart endoscopy, and data-guided surgery. These innovations, driven by artificial intelligence (AI), machine learning, big data analytics, and computational visualization, are generating a new paradigm in contemporary medicine (Miotto et al., 2021; Meskó et al., 2020).

1. Digital Biomarkers

Digital biomarkers are physiological and behavioral indicators collected through technologies such as smartwatches, biosensor patches, and mobile devices. Its clinical relevance lies in its ability to measure variables continuously, non-invasively, and remotely, which improves monitoring and early diagnosis of diseases (Coravos et al., 2020; Izmailova et al., 2020).

Unlike conventional biomarkers (such as blood glucose levels or tumor antigens), digital biomarkers can capture data on behavior, sleep, mobility, vocal patterns, heart rate, and physiological variability with high temporal resolution. They are especially useful in neurodegenerative diseases, mental disorders, cardiovascular disorders, and diabetes (Dorsey et al., 2020).

Table 1. Comparison between Conventional and Digital Biomarkers

Criterion	Conventional	Digital
Measurement Type	Specific Chemical/Physiological	Continuous physiological/behavioral
Collection Method	Biological sample (blood/urine)	Wearable sensors or mobile devices
Data Frequency	Occasional	Permanent / Real-Time
Invasiveness	Invasive	Non-invasive
Applicability	Clinical diagnosis	Prediction, prevention and monitoring

Source: Adapted from Coravos et al. (2020) and Izmailova et al. (2020).

2. Smart Endoscopy

Smart endoscopy consists of the integration of AI into endoscopic procedures, mainly through computer vision algorithms that detect precancerous or malignant lesions in the digestive tract (Garg et al., 2023; Wu et al., 2022). The CADx (Computer-Aided Diagnosis) and CADe (Computer-Aided Detection) systems allow endoscopists to be assisted in real time, reducing errors of omission and increasing diagnostic sensitivity.

Multicenter clinical studies have shown that the use of AI in colonoscopies significantly increases the adenoma detection rate (ADR), a key metric in colorectal cancer prevention. For example, Yamada et al. (2023) reported an increase in ADR from 25% to 35% in centers that implemented this technology.

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Table 2. Clinical Benefits of AI Endoscopy

Benefit	Evidence/Results	Fountain
Increased detection rate	10–15% improvement in ADR in colonoscopy	Yamada et al. (2023)
Reduced variability	Reduced dependence on the human operator	Garg et al. (2023)
Real-time assisted diagnosis	Automated identification of polyps, ulcers, and flat lesions	Wu et al. (2022)
Optimizing Surgical Flow	Reduced visual interpretation time	Meskó et al. (2020)

3. Data-Guided Surgery

Data-guided surgery combines three-dimensional visualization tools, intraoperative sensors, and predictive models to improve surgical accuracy. Artificial intelligence makes it possible to predict complications, simulate scenarios, and guide surgical procedures in real time using assisted navigation or augmented reality (Hashimoto et al., 2022; Liew et al., 2022).

For example, in neurosurgery, 3D neural maps generated from functional magnetic resonance imaging (fMRI) are used to plan safe routes of intervention. In orthopedics and spinal surgery, computerized navigation systems allow implants to be placed with millimeter precision, reducing operative time and postoperative complications (Zhou et al., 2021).

Table 3. Clinical Applications of Data-Guided Surgery

Medical Specialty	Specific Application	Technology used	Clinical Outcome
Neurosurgery	Tumor Resection Planning	3D + fMRI + AR models	Reduced cortical damage
Spinal surgery	Pedicle screw placement	Computer navigation + AI	Higher accuracy and lower complication rate
Liver surgery	Segmental anatomical resection	Volumetric Reconstruction + Simulation	Less intraoperative bleeding

Source: Hashimoto et al. (2022), Liew et al. (2022), Zhou et al. (2021).

Methodology

This study is based on a **qualitative-descriptive methodological approach** and **systematic review**, aimed at examining the state of the art on the integration of digital biomarkers, intelligent endoscopy and data-guided surgery in contemporary medical diagnosis. The choice of this approach responds to the need to synthesize recent knowledge on emerging technologies that have significantly impacted the clinical ecosystem, particularly during the post-pandemic period (Sarker et al., 2021; Topol, 2019).

Research Design

A systematic review of scientific literature **was used** in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which ensured methodological rigor and traceability in the selection and analysis of studies (Page et al., 2021).

Table 1. Research Design Parameters

Parameter	Description
Type of study	Systematic review and documentary analysis
Methodological approach	Qualitative descriptive
Time frame	Publications between 2019 and 2024

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Selection criteria	Peer-reviewed studies with clinical samples and empirical evidence
Protocol followed	PRISMA Guidelines

Sources and search criteria

High-impact academic databases such as **PubMed, Scopus, Web of Science** and **IEEE Xplore** were consulted, using Boolean combinations with the following descriptors:

- ("digital biomarkers" AND "diagnosis")
- ("AI-assisted endoscopy" OR "smart endoscopy")
- ("data-driven surgery" OR "surgical navigation systems")
- ("precision medicine" AND "AI healthcare")

Selected articles had to meet the following **inclusion criteria**:

- Publication date between January 2019 and May 2024.
- Peer-reviewed.
- Empirical approach in clinical applications.
- Language: English or Spanish.

Duplicate articles, narrative reviews without systematic analysis, and documents without access to the full text were excluded.

Selection process

The initial search yielded 214 articles. After applying automatic and manual filters, duplicates and irrelevant posts were removed. Finally, 47 studies that met all criteria were selected for detailed analysis.

Table 2. Study Selection Process (PRISMA model)

Stage	Number of Studies
Identified in the initial search	214
Deduplication	-34
Title and abstract review	-82
Full-text review	-51
Studies included for final analysis	**47**

Source: Authors' elaboration based on Page et al. (2021).

Analysis strategy

The selected studies were coded through **thematic analysis**, with emphasis on the following axes:

- Clinical applications of digital biomarkers.
- Clinical outcomes with AI-assisted endoscopy.
- Surgical precision and efficiency with data-guided surgery.
- Advantages, limitations and barriers of technological implementation.

An Excel analysis matrix was used to identify common patterns, emerging trends, and knowledge gaps.

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Research Article

Table 3. Thematic Axes of Documentary Analysis

PARENT TOPIC	VARIABLES ANALYZED
DIGITAL BIOMARKERS	Sensor type, accuracy, monitoring frequency, pathologies
SMART ENDOSCOPY	ADR, error rate, AI type, procedure time
DATA-GUIDED SURGERY	Surgical specialty, type of technology, clinical impact
LIMITING FACTORS	Cost, regulation, interoperability, technical training

RESULTS

Analysis of the 47 selected studies revealed a significant clinical impact on the application of digital biomarkers, smart endoscopy, and data-guided surgery. Below are the results organized by technology, with an emphasis on quantitative indicators of diagnostic efficiency, clinical accuracy, and operational improvement.

1. Results in the use of digital biomarkers

Digital biomarkers showed high clinical utility in contexts of continuous monitoring and early diagnosis, particularly in neurological, cardiometabolic and sleep disorders.

A longitudinal study with patients with Parkinson's disease showed that motion sensors could detect motor fluctuations with an accuracy of 87% (López et al., 2022). Likewise, monitoring of cardiac variability in patients with chronic heart failure predicted adverse events with a sensitivity of 82% and a specificity of 79% (Mahadevan et al., 2021).

Table 1. Clinical Impact of Digital Biomarkers

Medical Condition	Digital Biomarker	Diagnostic Accuracy	Reference
Parkinson	Wrist accelerometers	87%	López et al. (2022)
Heart failure	HR variability	Sens. 82%, Esp. 79%	Mahadevan et al. (2021)
Sleep disorder	EEG pattern analysis	90%	Kumari et al. (2020)
Moderate-severe depression	Physical activity + voice	78%	Jacobson et al. (2023)

2. Results of AI-assisted smart endoscopy

Artificial intelligence (AI)-assisted endoscopy systems showed substantial improvements in **adenoma detection rate (ADR),** which is a key indicator in colorectal cancer prevention. According to Yamada et al. (2023), ADR increased from 25% to 36% with the use of AI in routine colonoscopies. In addition, errors of omission were reduced by 31% compared to human endoscopists without digital assistance (Wu et al., 2022).

In clinical contexts, the mean time to detect and classify lesions also decreased by an average of 18 seconds per case, optimizing the operational load.

Table 2. Results of Smart Endoscopy

Clinical Indicator	No AI	With AI	Change (%)	Fountain
Adenoma Detection Rate (ADR)	25%	36%	+44%	Yamada et al. (2023)
Errors of omission	17%	11.7%	-31%	Wu et al. (2022)
Mean time per detected lesion	42 sec	24 sec	-43%	Garg et al. (2023)

3. Results of Data-Guided Surgery

Data-guided surgery has allowed greater surgical precision, reduction in postoperative complications and a decrease in surgical times. In spinal surgery, the use of AI-assisted computational navigation increased the accuracy in pedicle screw placement from 89% to 97%, according to Liew et al. (2022). In liver surgery, 3D organ reconstruction facilitated more accurate resections, reducing bleeding by an average of 200 ml per intervention (Zhou et al., 2021).

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In addition, the use of predictive AI models made it possible to anticipate postoperative complications with a sensitivity of 84% and specificity of 81% in major digestive surgeries (Hashimoto et al., 2022).

Table 3. Data-Guided Surgery Results

Indicator	*Value without AI / 3D*	*Value with AI / 3D*	*Improvement (%)*	*Fountain*
Precision in Spinal Surgery	89%	97%	+9%	Liew et al. (2022)
Bleeding in liver surgery	620 ml	420 ml	-32%	Zhou et al. (2021)
Prediction of complications (digestive)	Sens. 66%, Esp. 64%	Sens. 84%, Esp. 81%	+25% / +26%	Hashimoto et al. (2022)
Average Surgical Time (Spinal)	180 min	150 min	-16.7%	Chen et al. (2023)

General Summary of Results

The set of results indicates that technological integration improves diagnostic accuracy, reduces clinical errors, shortens procedure times and allows safer and more personalized interventions. These improvements are consistent across various medical specialties, supporting the staggered adoption of these tools in inpatient and outpatient settings.

CONCLUSIONS

The digital transformation of medical diagnosis, through the integration of digital biomarkers, intelligent endoscopy, and data-guided surgery, represents a paradigm shift that has a transversal impact on the accuracy, efficiency, and personalization of health care. The evidence collected in this research shows that these emerging technologies have substantially improved clinical outcomes, reducing diagnostic errors, optimizing surgical times and allowing for more predictive and proactive medical care.

First, **digital biomarkers** have revolutionized clinical monitoring by offering continuous, real-time data without direct patient intervention. This modality has allowed the early identification of physiological alterations in contexts such as Parkinson's, heart failure, and mental health (López et al., 2022; Mahadevan et al., 2021). The digitization of these biomarkers also allows the data to be integrated into artificial intelligence platforms to make personalized clinical predictions (Jacobson et al., 2023).

Second, the implementation of **smart endoscopy** has had a particularly noticeable impact on increasing the adenoma detection rate and reducing diagnostic variability. Recent studies support that AI-assisted CADe and CADx systems not only improve sensitivity, but also reduce the time needed to identify lesions in gastrointestinal procedures (Yamada et al., 2023; Wu et al., 2022). This technology is emerging as an emerging standard in endoscopic procedures.

In addition, **data-guided surgery** has significantly optimized intraoperative safety and postoperative outcomes. Technologies such as computational navigation, 3D visualization, and predictive AI models have been shown to improve surgical precision in specialties such as neurosurgery, digestive surgery, and orthopedics (Hashimoto et al., 2022; Liew et al., 2022). These systems not only benefit patients, but also reduce surgical stress and the decision burden for healthcare professionals.

However, in order to consolidate the widespread adoption of these technologies, several structural challenges need to be **addressed**. These include: interoperability of systems, protection of patient data, technical training of clinical staff, and the creation of regulatory frameworks that support the ethical use of artificial intelligence in medicine (Meskó et al., 2020; Hashimoto et al., 2022).

In conclusion, the digital transformation of medical diagnosis is not an ephemeral trend, but a structural evolution of the health ecosystem that is redefining contemporary clinical practices. Healthcare institutions that are committed to the safe and ethical integration of these technologies will be better positioned to offer more efficient, personalized and evidence-based medical care.

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Research Article

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