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COMMENTARY

Data-Driven Culture in Medicine and Surgery: Policy Pathways to Learning Health Systems

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Abstract: The transition toward data-driven medicine represents a structural inflection point for health systems, redefining how quality, equity, and innovation are jointly pursued. Robotic-assisted surgery, when integrated within real-world data infrastructures and effective governance, should be understood not merely as a technological upgrade but as a policy instrument capable of transforming surgical delivery at scale. The diversification of robotic platforms following patent expiration has altered the economic and strategic calculus, enabling broader adoption beyond elite or private settings. Brazil's decision to incorporate robotic-assisted radical prostatectomy into its Unified Health System (SUS) exemplifies how universal health systems can intentionally integrate advanced surgical technologies with equity objectives, industrial development, and national innovation strategies. This policy-oriented conceptual analysis synthesizes selected literature, policy frameworks, and health system experiences to examine the governance, implementation, and equity implications of data-driven surgery, with an emphasis on universal health systems and low- and middle-income countries. We argue that from a global health and policy perspective, data-driven surgery should be governed as a public asset, anchored in transparency, interoperability, and outcomes accountability, rather than as a market-driven luxury. Real-world data capture has enabled the systematic assessment of surgical performance, the personalization of care pathways, and the scaling of best practices across institutions. In principle, these developments offer a pathway toward more precise, efficient, and equitable surgical care. Health systems that fail to integrate robotics, artificial intelligence, and data governance risk widening inequities and forfeiting innovation sovereignty. Conversely, those that adopt a system-level, policy-led approach can transform surgical care into a lever for both population health and sustainable technological development. Challenges include digital infrastructure gaps, workforce readiness, regional disparities, and ethical concerns related to data governance and privacy.

Keywords: data-driven medicine, Surgical public health, robotic-assisted surgery, universal health systems, artificial intelligence, health economic-industrial complex, real-world, innovation policy

Introduction

The culture of medicine and surgery is undergoing a fundamental transformation. Clinical decision-making, once grounded predominantly in individual expertise, intuition, and apprenticeship, is increasingly expected to be transparent, measurable, and continuously improvable. Medicine is shifting from an art centered on individual mastery to a system of collective intelligence, where learning is embedded not only in practitioners but in institutions and health systems themselves. Surgery, long regarded as the epitome of tacit skill and personal judgment, now sits at the forefront of this transition, as procedural performance, outcomes, and workflows become digitally captured, analyzed, and fed back into practice.[1]

This transformation is inseparable from the rise of data as a core infrastructure of care. In contemporary surgical practice, data are no longer passive by-products of clinical activity; they function as active instruments of quality improvement, accountability, and system redesign. Advances in digital platforms, robotics, artificial intelligence, and real-world data capture have enabled the systematic assessment of surgical performance, the personalization of care pathways, and the scaling of best practices across institutions. In principle, these developments offer a pathway toward more precise, efficient, and equitable surgical care.

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Implementation is not automatic and is constrained by factors such as financing, regulation, industrial dependence, and workforce readiness. Without clear policy direction, data-driven technologies may exacerbate fragmentation, vendor lock-in, and inequities, rather than strengthening learning health systems, particularly in universal health systems and low- and middle-income countries. Accordingly, a data-driven culture in medicine and surgery must be treated as a policy and systems challenge, requiring intentional governance, public investment, and alignment between data infrastructure, clinical practice, and societal goals.

Using surgery as a paradigmatic case, this commentary illustrates how policy can actively steer data-driven transformation toward equity, sustainability, and collective learning, positioning health systems not simply as adopters of technology but as architects of intelligent care. This manuscript adopts a policy perspective and conceptual analysis based on a focused narrative synthesis of the literature and relevant policy frameworks on data-driven medicine, surgical innovation, and learning health systems. Drawing on selected peer-reviewed studies, policy documents, and health system experiences, the analysis examines governance, implementation, and equity implications, with particular emphasis on universal health systems and low- and middle-income countries.

The Data Revolution in Surgical Care

Over the last two decades, digitalization has redefined clinical decision-making. From electronic health records to interoperable databases, and from artificial intelligence (AI) assisted diagnostics to surgical robotics (eg, intraoperative decision support, skill assessment, workflow optimization), medicine is increasingly governed by continuous, real-world data. This evolution marks a transition from anecdote to analytics, and from volume to value. Data-driven health systems have been shown to improve patient safety, procedural outcomes, and system-level accountability. In surgery, the advent of high-fidelity intraoperative data capture, including kinematic, video, and sensor-based streams, enables the objective quantification of surgical performance.[2]

These datasets are now being used to develop predictive models for patient outcomes, surgical skill assessment, and even adaptive robotic automation. Such approaches are redefining surgical training and credentialing in terms of measurable, reproducible standards of excellence. The traditional hierarchy of surgical knowledge, observation, replication, and refinement is giving way to a data-driven learning cycle. Advances in digital health, real-world data capture, and artificial intelligence enable surgeons and health systems to transition from anecdotal experience to quantifiable performance and adaptive learning. Surgical registries, electronic health records, and wearable technologies are merging into vast datasets that reveal trends once invisible: disparities in access, variation in outcomes, and the nuanced interplay between human and system factors.[3,4]

From Robotics to Public Health: The New Surgical Frontier

Robotic-assisted surgery is a prime example of data-driven innovation. Since its introduction in the early 2000s, the da Vinci® platform (Intuitive Surgical Inc). has accumulated over 14 million procedures worldwide, generating a unique dataset on human-machine interaction, surgical precision, and patient outcomes. However, the field has long been constrained by patent protection and high capital costs, limiting adoption primarily to high-income settings. The expiration of key robotic platform patents between 2019 and 2022, means lower cost access, and new entrants such as Medtronic (Hugo), CMR Surgical (Versius), and Johnson & Johnson (Ottava) have begun to reshape the competitive landscape.[5]

Brazil's recent incorporation of robotic-assisted radical prostatectomy (RARP) into the *Sistema Único de Saúde*, SUS (Portaria SECTICS/MS No. 72, 2025), following a robust CONITEC recommendation, illustrates this paradigm shift. Beyond expanding access to minimally invasive surgery, it signals a strategic vision: leveraging high-cost technology as a catalyst for industrial policy, local capacity building, and health data sovereignty. This is not merely the adoption of an advanced surgical tool; it represents a commitment to data-driven policy, in which every procedure becomes a data point within a population-based ecosystem, allowing for the real-world assessment of effectiveness, quality, equity, and value at scale. This transition presents an opportunity for universal health systems, such as Brazil's SUS, the UK's NHS, and Canada's Medicare, to negotiate equitable access, stimulate domestic innovation, and integrate robotics within value-based frameworks.[6]

The Learning Health System in Action: Integrating Data, Quality, and Equity

A data-driven culture transforms the health system itself into a learning organism. In such a model, information flows continuously between the bedside, the operating room, and policy decision-making spheres. Clinical outcomes inform training standards, population health data shape resource allocation, and feedback loops between the public and private sectors stimulate innovation. For surgery, this means that every intervention contributes to a cycle of improvement, from surgical planning and intraoperative precision to postoperative recovery and long-term survivorship. The integration of robotic surgery within the SUS in Brazil offers an unprecedented opportunity to build this cycle using real-world evidence, ensuring that advanced technology serves both clinical excellence and social equity. A true data-driven surgical culture must transcend individual technologies to integrate the principles of quality, effectiveness, and equity. For universal health systems, this requires coordinated strategies encompassing data infrastructure, governance, and workforce training. The World Health Organization's Global Initiative for Emergency and Essential Surgical Care (GIEESC) and the Lancet Commission on Global Surgery have both emphasized that surgical metrics should inform national health planning and resource allocation, particularly in low- and middle-income countries.[7]

The convergence of real-world data and robotics also raises important ethical and regulatory considerations: data privacy, algorithmic bias, and the need for transparent validation frameworks. Global collaboration will be essential to harmonize these standards and ensure that AI and robotic platforms serve the goals of universal health coverage. Just as the scalpel once revolutionized anatomy, data is now the most powerful instrument in modern surgery. High-fidelity imaging, sensorized tools, and machine learning models enable predictive analytics, personalized risk assessment, and informed decision-making. Beyond the individual patient, aggregated data can identify which innovations deliver true value, not only in terms of patient survival and function, but also in accessibility and cost-effectiveness. A data-driven culture ensures that these initiatives are guided not only by market forces but also by measurable health impact and strategic sovereignty.[8]

Data-Driven Culture

Building a data-driven culture also demands ethical and professional evolution. Data stewardship, the responsible collection, sharing, and interpretation of clinical data, must be as integral to surgical training as anatomy or physiology. Transparency, reproducibility, and patient trust become the new pillars of professional excellence. Ultimately, data does not replace judgment; it refines it. It empowers clinicians to align intuition with evidence, individual skill with collective intelligence, and technology with humanity. Within the process of implementing a data-driven culture, it is essential to have highly skilled professionals capable of connecting information generated by machines with that produced by humans (patients and surgeons).[9]

Therefore, the presence of a pragmatic-minded surgeon, capable of translating clinical information into digital data, is of utmost value. In robotic surgery technology, considerable discussion has centered on the physical connection between the robot and the human through the Internet of Things (IoT), involving sensors, imaging enhancement, and motion analysis. However, the human–robot interaction extends far beyond a mere physical relationship. Implementing a data-driven culture in surgery, particularly in the era of robotics, requires redefining the ideal surgeon of the past century. More than relying on a single, dominant, and monopolizing surgeon, the new data-driven era demands a leader, a manager of professionals committed to valuing data and promoting continuous teamwork.[10]

For over 500 years, humans have sought to answer specific questions, compare groups, and assess the effects of treatments. While this type of reasoning remains essential within the concept of a data-driven culture, the data flow must be broader, capable of incorporating semi- or fully automated real-world data into the vastness of Big Data. For this transformation to occur, organizational structures must be modernized, as in the business world, thereby emphasizing the value of professionals with pragmatic minds.[11]

The data-driven surgical model relies on a robust digital infrastructure that supports reliable data capture, clear data governance (including privacy protections, accountability frameworks, and national data infrastructure), and interoperability standards, thereby providing an integrated view of surgical volume to facilitate continuous learning. It assumes institutional commitment, clinician engagement, and workforce readiness to use data in practice, as well as policy environments, particularly

in universal health systems that align incentives with quality, equity, and long-term system learning rather than short-term productivity. The next frontier of surgical progress will not be defined by new instruments alone, but by how intelligently we use the data they generate. A culture of data-driven medicine and surgery ensures that innovation serves not only the few who can afford it, but the many who need it.

Future Directions

The coming decade is likely to shift surgical systems from passive data accumulation toward more actionable forms of data intelligence, including AI-assisted performance analytics, predictive perioperative decision support, and progressively automated robotic functions. However, translating these capabilities into routine practice remains uneven and is constrained by factors such as cost, data quality, interoperability, workforce readiness, and regulatory capacity. Real-world feasibility, therefore, depends less on technological maturity than on governance choices that treat clinical data as a shared public asset rather than a proprietary by-product.

A data-driven culture in medicine and surgery should be understood not as a distant aspiration, but as a conditional necessity for 21st-century health systems, one that requires deliberate policy alignment to ensure that digital transformation advances not only technical precision, but also accountability, equity, and the foundational principles of universal care.

Disclosure

The authors report no conflicts of interest in this work.

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