A Comparative Analysis Of Competitors In The Field Of Laparoscopic Robotic Surgery

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ABSTRACT

Robotic-assisted surgery is the future of laparoscopic surgery. However, due to the rising number of systems on the market, this paper aims to inform potential buyers of an RAS about the characteristics and strengths of select industry competitors. Robotic surgery is a type of surgery that uses robotic-assisted surgery (RAS) systems to perform procedures with increased precision. Specifically, this paper aims to analyze three surgical robots and 1 mechanical system using various metrics to evaluate their overall performance and accessibility. These platforms, ranging from hundreds to millions of dollars, include modular robotics systems and handheld purely mechanical systems. I hope to provide a basis for prospecting organizations considering the acquisition of an RAS to improve patient care while balancing constraints such as cost and space.

INTRODUCTION

As surgical techniques advance toward higher precision and lower invasiveness, robotic-assisted systems have become essential tools in operating rooms worldwide. This paper critically evaluates three prominent robotic platforms—Da Vinci, Versius, and Hugo RAS—alongside a mechanical alternative, Axius. While the Da Vinci system dominates the market with its technical sophistication, it remains cost-prohibitive and operationally intensive for many healthcare institutions. By comparing these systems across clinical effectiveness, cost, modularity, ergonomics, and maintenance requirements, this analysis aims to identify a balanced framework for future robotic systems—one that enhances surgical capability while ensuring broader accessibility and sustainable operation.

BACKGROUND: WHAT IS ROBOTIC SURGERY?

Surgery is a specialized branch of medicine focused on diagnosing and treating diseases and conditions through operative or manual procedures. It encompasses a wide range of techniques, from traditional open surgery to the latest advancements in minimally invasive procedures. Recently, a modern surgical approach, called robotic surgery, utilizes robotic-assisted systems to perform procedures with enhanced precision, flexibility, and control. These robotic limbs are operated with the guidance of a surgeon, and there are currently no fully autonomous robotic surgical procedures approved or in practice.

Origins of Robotic Surgery

The inception of robotic surgery dates to 1985 when the PUMA 560 system was used for a neurosurgical biopsy. Subsequent developments led to the emergence of systems like ROBODOC, AESOP, and Zeus, which laid the groundwork for robotic-assisted surgery. However, these early models were gradually phased out by the early 2000s as the Da Vinci Surgical System rapidly advanced and became the dominant force in the field. Although Da

Vinci has maintained its market leadership, numerous competitors have emerged, challenging its supremacy with innovative alternatives [1].

Benefits of Robotic Surgery

Robotic surgery offers several advantages over traditional surgical methods. It minimizes the repetitive strain on surgeons, enhances surgical dexterity through highly articulated instruments, and enables minimally invasive techniques, contributing to faster recovery times and reduced postoperative complications [1]. These benefits have led to the wide adoption of robotic-assisted surgical procedures across various medical disciplines.

Leading Robotic Surgical Systems

The Da Vinci Surgical System [2], developed by Intuitive Surgical, remains the industry leader in robotic-assisted surgery. It is widely used across multiple surgical specialties, offering high precision and improved patient outcomes [3].

Other notable robotic surgical systems, which will be discussed in more detail in this report, include:

- Versius [4]: A modular robotic system by CMR Surgical, offering improved adaptability and usability in various surgical settings
- Axius [5]: A purely mechanical, handheld surgical device developed by FlexDex, allowing surgeons to perform complex procedures with enhanced dexterity at a lower cost. Although Axius is not strictly a surgical robot, it still provides similar albeit fewer functionalities to the other robots listed here.
- Hugo RAS [6]: A robotic-assisted surgery system developed by Medtronic, designed for minimally invasive procedures across multiple surgical disciplines

With these evolving technologies, the field of robotic-assisted surgery continues to expand, offering new possibilities for improving patient care and surgical outcomes.

This analysis of surgical robots covers key aspects, including clinical effectiveness across various procedures and specialties, a cost-benefit analysis considering acquisition and maintenance, an assessment of precision and ergonomics relating to technical design, and an overview of usage rate and accessibility based on factors like training requirements and hospital resources.

Clinical Effectiveness

Da Vinci demonstrates high clinical effectiveness, with reduced complication rates and shorter recovery times in complex surgeries like prostatectomies and hysterectomies [14]. Its advanced 3D visualization and "EndoWrist" technology contribute to superior surgical outcomes [2]. Versius is effective in various minimally invasive surgeries, with clinical studies suggesting lower postoperative pain and faster recovery times [15]. Its flexible port placement and ergonomic design enhance surgical precision, particularly in cholecystectomy procedures [15]. Axius is effective for laparoscopic and suturing tasks, offering precision at a low cost. While it lacks

advanced automation, its direct control allows for precise maneuvers in simpler surgical settings [8]. Hugo RAS demonstrates effectiveness across multiple specialties, but data on specific advantages over competitors is limited [16, 17]. Initial studies suggest comparable outcomes to established systems, but more extensive data are needed to validate its specific clinical benefits [16, 17].

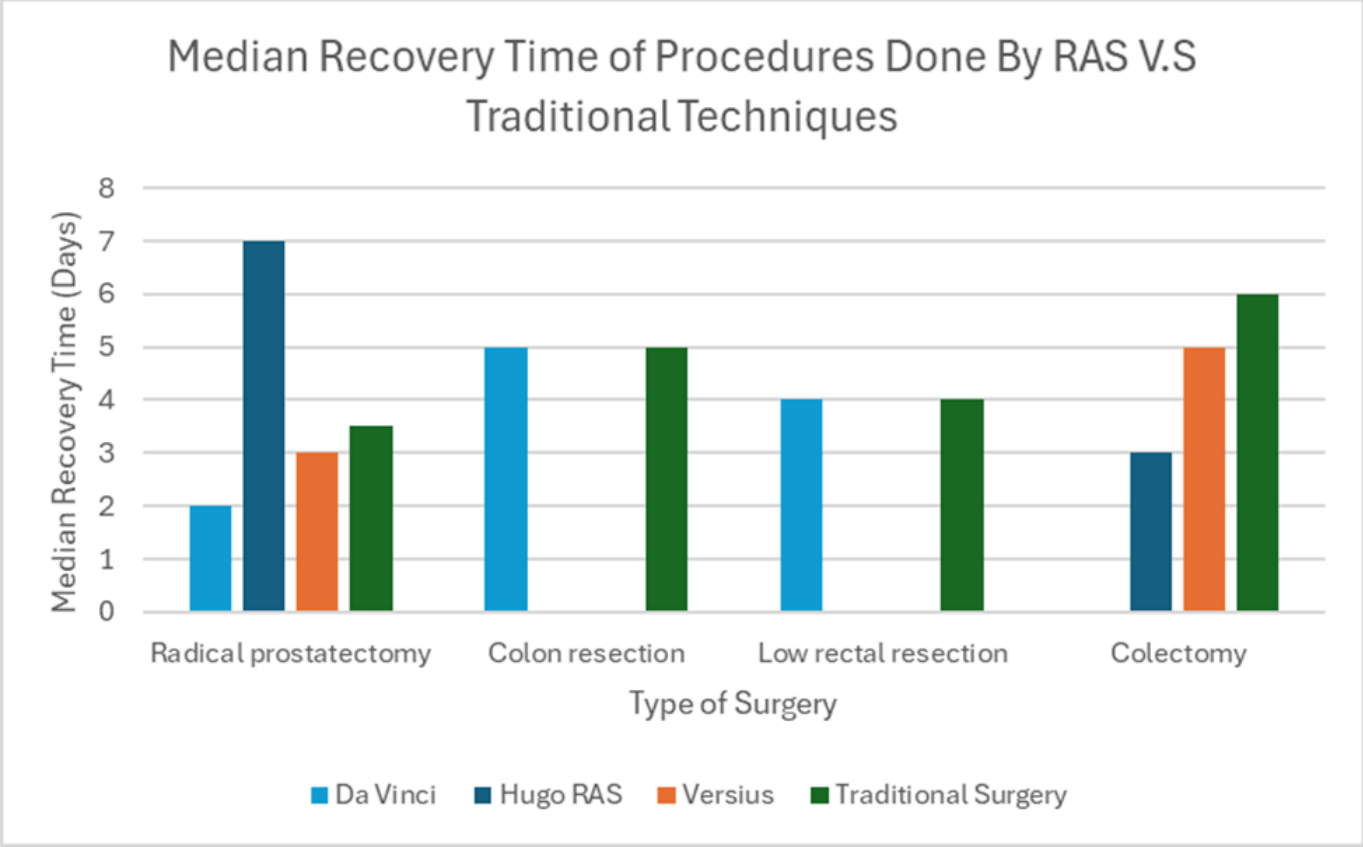

Figure 1: Median Postoperative Hospital Stay (in Days) for Radical Prostatectomy and Colectomy Across Robotic Platforms Compared to Traditional Surgery. Data primarily reflects outcomes from clinical trial groups for the Da Vinci Xi, Hugo RAS, and Versius systems, alongside benchmark figures from traditional surgical recovery sources. [25][26][27][28][29][30][31][32][33]

Tool Accessibility and Flexibility

Da Vinci is primarily accessible to high-budget hospitals and academic centers due to its high costs, including initial acquisition, maintenance, and instrument expenses. This limits its availability in smaller or resource-constrained facilities [7, 18]. Versius is highly accessible to smaller and mid-sized hospitals due to its lower cost, compact design, and easy integration [7, 11, 12]. Its modularity allows for a flexible setup in operating rooms with limited space, making it an attractive option for a broader range of hospitals [11, 12]. Axius is the most accessible option for low-resource hospitals, with its affordability making it suitable for widespread adoption [13]. The minimal setup and mechanical design make it easy to integrate into existing surgical workflows [13]. Hugo RAS is more affordable than Da Vinci but may require infrastructure

upgrades for optimal use [7, 19]. Its modular design and multi-specialty capabilities make it a versatile option for hospitals seeking to expand their robotic surgery programs gradually [6].

Cost-Benefit Analysis of Studied RASs

Da Vinci has a high initial acquisition cost ($1.5-$2 million) and significant ongoing expenses, justified by improved patient outcomes and efficiency in well-funded hospitals [7, 9]. The system's advanced capabilities and established training programs support its cost-effectiveness in high-volume surgical centers [2, 10]. Versius has a moderate initial cost ($0.75-$1 million) and lower maintenance due to modularity, making it ideal for hospitals with limited space and moderate budgets [4, 7]. Its design and versatile applications make it an attractive option for facilities seeking to optimize their surgical resources [11, 12]. Axius has very low acquisition ($500) and operational costs and is best suited for low-resource settings or smaller hospitals needing cost-effective, precision-enhancing tools [8, 13]. Its simplicity and minimal maintenance requirements make it a practical solution for facilities with limited budgets [8, 13]. Hugo RAS has a moderate initial cost ($0.9-$1.2 million) and lower maintenance due to modularity, suitable for hospitals with limited space and budget, allowing gradual integration of robotic surgery [6, 7]. Its modular design and multi-specialty capabilities provide a balance of cost-effectiveness and performance, appealing to hospitals seeking to expand their robotic surgery programs strategically [6]. Aside from the initial acquisition, each robotic surgery system has recurring costs in the form of end manipulators and routine maintenance.

Surgical System	Instrument Lifespan	Reusability	Cost Implications	Total Acquisition Cost
Da Vinci 5	10 uses (Base) [24] 12–18 uses (Extended Use Program) [20]	Reusable	Reduced per-use cost through extended lifespan	$1.5 - $2 Million
Hugo RAS	Replaced every 40–50 minutes [21] (Product is too new to tell; however, scissors have a	Not enough information is available	Potentially higher per-procedure cost, mitigated	$0.9 - $1.2 Million

	surprisingly short lifespan.)		by pricing strategies	
Versius	Projected 13 uses [15]	Reusable	Lower per-procedure cost due to extended lifespan	$0.75 - $1 Million

Table 1: The Da Vinci systems are more expensive for institutions to acquire due to their ongoing research and development into new systems, production costs, and software upgrades. The Hugo RAS has a comparatively lower price due to being developed using Da Vinci research.

DISCUSSION OF LITERATURE FINDINGS

Modularity

Robotic surgical systems can generally be categorized into single-platform systems and modular systems. A single-platform system, such as the Da Vinci Surgical System, is an all-in-one robotic solution where all robotic components (arms, console, and vision system) are integrated into a unified setup. Conversely, modular systems, such as Versius and Hugo RAS, allow hospitals to integrate robotic components individually, allowing for customized configurations based on specific surgical needs and infrastructure. So, what are their benefits? A single-platform system offers a standardized setup, ensuring consistent performance and seamless integration of robotic components. However, it typically comes with a higher cost ($1.5-$2 million for the Da Vinci) and requires significant training due to its complexity. In contrast, a modular system provides greater flexibility in deployment, allowing hospitals to add robotic capabilities gradually based on budget and procedural demand. Systems like Versius and Hugo RAS reduce initial financial burden ($0.75-$1.2 million), making robotic surgery more accessible to mid-sized and smaller hospitals.

Scalability and Cost Efficiency

Single-Platform systems require full system acquisition, making it costly for hospitals that only need robotic assistance for a limited number of procedures. Additionally, maintenance and instrument replacement costs are higher. In contrast, by choosing a modular system, hospitals can gradually invest in robotic components, starting with a basic setup and adding more robotic arms or imaging modules as needed. This reduces the short-term financial burden and allows hospitals to optimize their spending. This flexibility makes modular systems more financially accessible for smaller hospitals and clinics, leading to broader adoption of robotic surgery.

Training and Learning Curve

Due to high system complexity, hospitals must invest heavily in training programs, which can delay implementation. For example, Surgeons often need to undergo extensive training to master the Da Vinci system. Conversely, most modular systems are designed to mimic traditional laparoscopic techniques, which allows for faster surgeon adaptation. This allows for quicker integration into hospital workflows, reducing downtime and improving surgical team efficiency.

INSTRUMENT LIFESPAN

Instrument lifespan is a critical factor in evaluating the cost-effectiveness and operational efficiency of robotic surgical systems. It influences not only the per-procedure cost but also the scheduling and maintenance logistics within surgical departments.

The Da Vinci 5 system utilizes EndoWrist instruments, which are designed with embedded chips to monitor usage and ensure performance standards. Traditionally, these instruments were limited to 10 uses [24]. However, with the introduction of the Extended Use Program in October 2020, Intuitive Surgical extended the lifespan of certain high-volume instruments to 12–18 uses, depending on the specific instrument type [20]. This extension aims to reduce the per-use cost and enhance the value proposition for healthcare providers.

The Hugo RAS system, still early in development, features instruments that are currently single-use. For instance, the scissors used in procedures are designed for single use and are typically replaced every 40–50 minutes during surgery [21]. While this approach ensures optimal instrument performance, it may increase per-procedure costs. However, Medtronic has structured its pricing to mitigate these costs, ensuring that the frequent replacement of instruments does not impose additional financial burdens on healthcare facilities.

The Versius system by CMR Surgical employs instruments with a projected lifespan of 13 uses [15]. These instruments are designed to be sterilizable and reusable, aligning with the system's emphasis on modularity and cost-efficiency. The extended lifespan contributes to a lower per-procedure cost and supports the system's adaptability across various surgical specialties.

DIFFERENCES IN SURGEON CONSOLE ERGONOMICS

The ergonomics of the surgeon console has significant implications for comfort, learning curve, and procedural performance. Each system approaches console design differently, impacting usability in distinct ways.

Console Design and Immersion

The Da Vinci systems feature a closed console where the surgeon sits with their head inside a vision module. This offers superior 3D high-definition visualization and immersive control through foot pedals and finger-actuated hand manipulators [2, 3]. However, this fixed seated posture may contribute to musculoskeletal strain during long surgeries [2].On the other hand, the Versius system implements an open console that allows for both seated and standing operation, with controls designed to mimic laparoscopic instrument movements. This familiarity with traditional methods reduces physical fatigue and improves the ergonomics of surgeon

interaction [11, 12]. Similarly to Verisus, the Hugo RAS system offers a hybrid console with an open design and touch-based controls. It attempts to merge immersive visualization with physical flexibility, though long-term ergonomic outcomes remain under evaluation due to its recent market entry [6, 19]. In contrast to more complicated systems, Axius offers a simpler and less complex alternative to expensive robotic surgery platforms. This allows surgeons to use the tool like normal laparoscopic tools, thereby enhancing ergonomics by retaining similar hand movements [5, 8, 13].

Impact on Learning Curve and Surgeon Adaptation

Systems with intuitive controls and ergonomic familiarity—like Versius—shorten the learning curve and improve training throughput [12]. Da Vinci requires specialized training, often delivered through costly institutional programs, which can delay full-scale implementation and surgeon proficiency [10].

MAINTENANCE

Operational sustainability is tied closely to how easily systems can be maintained, serviced, and reintegrated into workflows following technical issues.

System Complexity and Maintenance Overhead

The Da Vinci systems require routine, high-cost maintenance. All components are proprietary, and Intuitive Surgical must perform most service operations. Instrument wear is tracked digitally, and tools typically require replacement after 10 uses, or up to 18 under the Extended Use Program [20, 24]. This significantly increases ongoing operating costs. Similarly, the Hugo RAS, while still new to the market, has components—like scissors—that are reportedly single-use and must be replaced every 40–50 minutes [21]. While Medtronic offers pricing schemes to mitigate this, the short tool lifespan may raise recurring expenses until long-term data suggests otherwise. Similar to Da Vinci, the Versius system's instruments can be reused approximately 13 times, and components like robotic arms are replaceable independently [15]. This reduces downtime and maintenance disruption while lowering per-procedure costs.

Downtime, Sterilization, and Workflow Integration

Modular Systems like Versius and Hugo RAS offer partial operation when one component is out of service. This modularity enhances system uptime and simplifies sterilization logistics [6, 11]. Axius: As a purely mechanical system, Axius requires minimal to no electronic maintenance. It is easily sterilized, highly durable, and does not depend on software updates or proprietary diagnostics, making it ideal for low-resource settings [8, 13].

CONCLUSION

Despite its technical and ergonomic superiority, the Da Vinci Surgical System's high cost and complex maintenance limit its accessibility to well-funded institutions. In contrast, modular alternatives like Versius and Hugo RAS offer a more adaptable and cost-conscious approach without significant compromise in clinical utility. The purely mechanical Axius platform also

demonstrates that affordability and precision are not mutually exclusive. Overall, Da Vinci is the most capable system on the market; however, due to its cost, Versius and Hugo RAS may be better choices for resource-limited institutions. Ultimately, the future development of surgical robotics lies in leveraging the strengths of these systems—combining Da Vinci's precision with the accessibility, usability, and economic feasibility of its competitors—to deliver skillful robotic surgery to a wider range of hospitals worldwide.

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