The Hippocratic Robot: Routinized Robot Adoption in Surgical Practice

Anna Maria Pretzsch

Dissertation written under the supervision of Professor Peter V. Rajsingh, PhD

Dissertation submitted in partial fulfilment of requirements for the MSc in Management with a specialization in Strategy, Entrepreneurship & Impact, at the Universidade Católica Portuguesa,

May 27, 2026

Abstract

Surgical practice is changing as new technologies evolve. This gives rise to surgical robotic systems, capable of executing intraoperative tasks independently. Despite their clinical and operational potential, widespread routinized adoption in hospitals remains limited. An exploratory sequential mixed-methods approach was conducted, combining literature with 15 interviews across three expert groups and a quantitative survey with 305 valid responses. The theoretical framework integrated the Unified Theory of Acceptance and Use of Technology, the Technology-Organization-Environment framework, Diffusion of Innovation, Resource-Based Theory, Dynamic Capabilities, and Trust Theory. The findings reveal that a dynamic, multi-dimensional interaction of different conditions drives routinized adoption. Organizational factors emerged as the dominant category deciding whether procurement translates into routinized adoption. Technical factors establish the adoption opportunity, with relative advantage as the primary driver, while interoperability and maturity constitute baseline requirements. At the individual level, performance expectation and peer-driven social influence are the diffusion mechanisms. Trust operates as a cross-cutting enabling condition across all levels. Patient acceptance functions as a structural prerequisite, as no procedural volume can be generated without patients' consent. Environmental factors set the boundary conditions within which the adoption is financially and regulatorily viable. Overall, the study identified that routinized adoption only materializes when all dimensions co-align, forming a sequential conditional logic.

Keywords: SASRS, Routinized Adoption, UTAUT, TOE, Trust

Title: The Hippocratic Robot: Routinized Robot Adoption in Surgical Practice

Author: Anna Maria Pretzsch

Resumo

A prática cirúrgica está a mudar à medida que as novas tecnologias evoluem, dando origem a sistemas robóticos cirúrgicos capazes de executar tarefas intraoperatórias de forma autónoma. Apesar do seu potencial clínico e operacional, a adoção rotineira nos hospitais continua limitada. Foi utilizada uma abordagem exploratória sequencial de métodos mistos, combinando literatura com 15 entrevistas e um inquérito quantitativo com 305 respostas válidas. O quadro teórico integrou o UTAUT, o quadro Tecnologia-Organização-Ambiente, a Difusão da Inovação, a Teoria Baseada em Recursos, as Capacidades Dinâmicas e a Teoria da Confiança. Os resultados revelam que a interação de diferentes condições impulsiona a adoção rotineira. Os fatores organizacionais emergiram como a categoria dominante, determinando se a aquisição se traduz em utilização clínica rotineira. Os fatores técnicos estabelecem a oportunidade de adoção, a vantagem relativa como principal impulsionador, enquanto a interoperabilidade e a maturidade constituem requisitos base. A nível individual, as expectativas de desempenho e a influência social entre pares são os mecanismos de difusão. A confiança funciona como condição facilitadora transversal a todos os níveis. A aceitação dos doentes constitui um pré-requisito estrutural, não sendo possível gerar volume de procedimentos sem o seu consentimento. Os fatores ambientais definem as condições-limite dentro das quais a adoção é financeira e regulatoriamente viável. O estudo identificou que a adoção rotineira se concretiza quando todas as dimensões se alinham, formando uma lógica condicional sequencial.

Palavras-chave: SASRS, adoção rotineira, UTAUT, TOE, confiança

Título: O Robô Hipocrático: Adoção Rotineira de Robôs na Prática Cirúrgica

Autora: Anna Maria Pretzsch

Acknowledgement

This thesis marks the completion of my master's program and the end of an incredible, challenging, and demanding two-year journey. Looking back, I am beyond grateful for the personal growth, the academic challenges, the late nights, and, most importantly, the people I met along the way, whom I can now call close friends. Completing this thesis marks not only an academic milestone but also the end of a very meaningful chapter in my life.

First and foremost, I would like to express my deepest gratitude to my parents for their constant support and unconditional belief in me. Thank you for always encouraging me, pushing me to do my best, and standing by me through the roller-coaster ride. Without you, this journey and this achievement would not have been possible. This milestone does not only belong to me, but also to you two.

Further, I want to thank my supervisor, Professor Peter V. Rajsingh, for his ongoing support, continuous guidance, and feedback. His insights have been valuable for this work and helped me grow academically. It was a privilege to work under his supervision, and I highly appreciate the time, effort, and work he dedicated to my thesis and me.

In addition, I am sincerely grateful to all interview partners for their time, insights, and openness. Their valuable experience and answers greatly contributed to this work. I also would like to thank my friends and everyone who accompanied me throughout these past two years. Your friendship made distance possible and created the best moments. I am grateful to have shared this journey with such wonderful people.

Finally, I want to thank the four readers who dedicated time and effort to carefully reviewing and identifying the small mistakes that I couldn't find. Without you, the errors would probably still be in this work, not giving it the final polish I hoped for.

Table of Contents

List of Figures

List of Abbreviations

AI	Artificial Intelligence
DC	Dynamic Capabilities
DL	Deep Learning
DOI	Diffusion of Innovation
DRG	Diagnosis Related Groups
LASR	Level of Autonomy in Surgical Robotics
MDR	Medical Device Regulation
ML	Machine Learning
MLR	Multiple Linear Regression
MT	Medical Technologies
OR	Operating Room
PEOU	Perceived Ease of Use
PU	Perceived Usefulness
RBT	Resource-Based Theory
SASRS	Semi-autonomous Surgical Robotic Systems
SOP	Standardized Operating Procedure
TAM	Technology Acceptance Model
TOE	Technology-Organization-Environment
UTAUT	Unified Theory of Acceptance and Use of Technology
VIF	Variance Inflation Factor

1 Introduction

“The integration of robotics and artificial intelligence (AI) is reshaping modern surgery, offering levels of precision, control, and intelligence once beyond reach” (Wah, 2025b, p. 1).

For decades, the operating room (OR) was defined by the steady hands of surgeons and the mechanical limits of traditional instruments. Currently, surgical practice is changing, particularly through advances in robotics and AI-enabled automation (Reddy et al., 2023; Wah, 2025b).

Widely developed and used across industries (Dachs et al., 2022), robotic systems are also seen in medical applications, including surgery. Robotic surgery has transitioned from a niche, experimental curiosity in the 1980s to a cornerstone of modern medicine (Biswas et al., 2023; Picozzi et al., 2024). The global robotic surgical market is forecast to reach USD 54.61 billion by 2034, implying a CAGR of 16.68% over 2026–2034 (Fortune Business Insights, 2026).

Key patents from a long-standing monopoly are expiring, enabling new generations of robotic platforms empowered by AI (Marcus et al., 2024; Picozzi et al., 2024). We are witnessing a fundamental shift from the traditional *master-slave* tool paradigm towards AI-based intraoperative applications (Vasey et al., 2023) or even semi-autonomous systems capable of perceiving the surgical environment (Liu et al., 2024). Different levels of autonomy range from task-level to complete autonomy, where the robot becomes the surgeon (Lee et al., 2024). These developments promise major clinical and operational benefits, but also raise questions about safety, accountability, and transparency (Wah, 2025b).

In an era defined by rising costs, an aging population, and a shrinking medical workforce (Landi et al., 2025; Wah, 2025b), robotics and automation are emerging as a solution. They provide higher precision and control, reduced blood loss, shorter hospital stays, and faster recovery (Biswas et al., 2023; Maynou et al., 2024; Reddy et al., 2023). However, technological progress appears to be outpacing patients and practitioners trust, particularly when models function as *black boxes* with limited transparency (O’Sullivan et al., 2019; Vasey et al., 2023). Yet, there are obstacles preventing the routine use of robots and AI in surgery, limiting their potential (Picozzi et al., 2024).

This research aims to answer the question: *What key drivers influence routinized adoption of semi-autonomous surgical robotic systems in hospitals?*

Adoption refers to institutionalization and routine use, and the focus is on semi-autonomous surgical robotic systems (SASRS). The scope of the analysis does not include traditional master-slave systems, nor the adoption potential of fully autonomous robotics, since full autonomy is in the more distant future.

Hospitals operate as firms defined by their bundle of resources and capabilities (Barney et al., 2021). SASRS can become a strategically valuable asset that provides advantages to adopters, while peer hospitals not implementing the technology risk falling behind.

Following the introduction, a literature review explores the evolution of surgical robotics and the application of theoretical frameworks. The Technology-Organization-Environment (TOE) framework, combined with the Unified Theory of Acceptance and Use of Technology (UTAUT), is used to explain institutional and individual factors influencing adoption. Diffusion of Innovation (DOI), Resource-Based Theory (RBT), and Dynamic Capabilities (DC) complete the theoretical backbone. The third chapter describes the mixed-methods approach used to answer the research question. The empirical findings from expert interviews and the survey are presented in Chapter 4. Finally, Chapter 5 discusses the results, their implications, and the study's limitations.

2 Literature Review

The following chapter provides definitions, foundational concepts, and the theoretical framework for understanding robotic surgery and adoption factors.

2.1 Robotic Surgery and Autonomy

This section introduces concepts of robotic surgery, including its evolution, degree of autonomy, and the clinical relevance of SASRS.

2.1.1 Definition of Robots

The field of surgical robotics is characterized by a lack of uniform standards and definitions (Klodmann et al., 2021). In general, the word *robot* comes from the Czech word *robota*, which translates to “forced labor” (Cao et al., 2024; Lanfranco et al., 2004). Definitions tend to focus less on human-like intelligence and more on observable system properties, such as programmability and autonomy. A robot can be defined as a “programmed actuated mechanism with a degree of autonomy … to perform locomotion, manipulation or positioning” (International Organization for Standardization, 2021).

In the medical field, robots range from tiny devices deployable inside the abdominal cavity to robots designed to interact with people (Khan & Anwar, 2020). Robotic surgery refers to any surgical procedure or technology in which a computer-supported device is introduced into the surgeon-patient interaction, taking over a portion of the operative control that was previously done by the surgeon (Herron et al., 2008). Technically, such devices are categorized as robotically assisted surgical systems with programmable moving parts designed to accurately position surgical instruments (Klodmann et al., 2021). They combine surgeon expertise with robotic technology to enhance the safety and quality of procedures through increased precision and dexterity (Reddy et al., 2023).

2.1.2 Evolution of Robotic Surgery

Surgical intervention has moved from manual constraints of open surgery (Kok Wah, 2025) to reduced invasiveness and increased precision. In traditional operations, clinical experience and surgeons’ skills matter, yet subjective bias, limited quality, and the nature of pre- and intraoperative imaging constrain results (Liu et al., 2024). One large opening is replaced by multiple small holes, known as laparoscopic or minimally invasive surgery (Liu et al., 2024).

The journey towards robotic surgery began in 1967 (George et al., 2018), with the first robot participating in human surgery in 1985. The Puma 560, an industrial arm, was used for CT-guided brain biopsies (Biswas et al., 2023; Chatterjee et al., 2024). The second milestone was in 2000 when the FDA cleared the da Vinci system for routine medical use (Biswas et al., 2023). It eventually became the dominant robotic surgical system (Knudsen et al., 2024). Da Vinci uses a master-slave teleoperation model in which surgeons control robotic arms that mimic hand movements with enhanced accuracy and stability (Chatterjee et al., 2024).

Although the master-slave paradigm has dominated robotic surgery for the last two decades, AI, machine learning (ML), and deep learning (DL) are facilitating a transition from passive instruments towards intelligent, active collaborators (Kok Wah, 2025; Saqib et al., 2025). Instead of mechanical execution, the system offers advanced image recognition, decision support mid-procedure, and even semi-autonomous task execution (Knudsen et al., 2024; Kok Wah, 2025). By analyzing large datasets of surgical videos, ML and DL can identify anatomical structures in real-time and predict surgical phases (Gumbs et al., 2021; Knudsen et al., 2024). Errors can potentially be reduced and outcomes standardized across different surgeon skill levels (Kok Wah, 2025; Liu et al., 2024). Consequently, the robot is evolving from a tele-manipulator to a collaborator (Kok Wah, 2025) that enhances performance and decision-making (Liu et al., 2024). This provides an opportunity for higher levels of surgical autonomy. But there are also risks, such as unintentional robot behaviors or errors that may result in physical injury or death (Attanasio et al., 2021).

2.1.3 Level of Autonomy

Across the literature, autonomy is considered a spectrum rather than a single feature. Fiorini et al. (2022) discuss levels of autonomy in terms of:

a) Who generates the option?
b) Who selects the option?
c) Who executes the option?
d) Who monitors the option?

This study adopts the Level of Autonomy in Surgical Robotics (LASR) framework, ranging from no autonomy (Level 0) to full autonomy (Level 5) (Lee et al., 2024).

Level 0: no autonomy means a robot is unable to make decisions or perform surgical actions independently. Procedures are either purely surgeon-driven or teleoperated, where the surgeon's commands are replicated by the robot (Yang et al., 2017). The surgeon is in full control, generating, selecting, executing, and monitoring all surgical actions at all times (Attanasio et al., 2021; Lee et al., 2024).

Level 1: robot assistance is where the robot provides supportive functions that can be cognitive (enhancing information) or physical (guiding motion) (Attanasio et al., 2021), while the surgeon has full control. Functions are designed to augment the surgeon's abilities rather than substitute human control. Level 1 robotics lays the groundwork for future autonomy by requiring elements of situational awareness. In the LASR taxonomy, Level 1 assistance can include passive support, such as tool tracking systems that provide the surgeon with additional information, or active guidance, such as haptic feedback systems (Attanasio et al., 2021; Lee et al., 2024). The surgeon has the responsibility and command authority (Lee et al., 2024).

Level 2: task autonomy marks a qualitative shift from continuous to discrete control (Attanasio et al., 2021; Lee et al., 2024). The surgeon initiates a specific, bounded task and provides the necessary parameters, while the robot executes and monitors the preprogrammed action independently (Lee et al., 2024). The aim is to reduce variability (Lee et al., 2024) and exhaustion (Attanasio et al., 2021). Typical examples include the automation of repeatable subtasks such as components of suturing (Yang et al., 2017). The surgeon remains in charge by supervising the results and intervening as needed, but they are no longer required to drive every movement during that specific task window (Yang et al., 2017).

Level 3: conditional autonomy transitions the robot from enhancer to performer (Khanna et al., 2025). Using patient-specific information (such as preoperative scans), the robot can independently generate and propose strategies for a task. The robot can execute the plan while monitoring the environment and updating the strategy within the defined scope, but the surgeon must approve or revise the suggested plan (Attanasio et al., 2021; Lee et al., 2024). While the robot has more agency in planning and executing than at Level 2, the human remains the final decision-making authority (Yang et al., 2017).

Level 4: high-level autonomy has robots making autonomous clinical decisions and executing them based on an optimal, patient-specific surgical plan generated from preoperative and intraoperative information (Attanasio et al., 2021). While human oversight is present, the robot's decision-making and independence increase substantially (Khanna et al., 2025). The surgeon is only supervising, but he can still take over control if necessary (Lee et al., 2024). No systems are yet in service.

Level 5: full autonomy has autonomous robotic systems performing entire surgical procedures without human input, including generating and selecting the operative plan as well as handling unforeseen conditions independently. Human oversight becomes optional rather than mandatory. No systems are yet in operation because they raise the most profound legal, ethical, and regulatory questions (Lee et al., 2024).

Level 2 and 3 surgical robots are considered "within reach of today's technology" (Fiorini et al., 2022, p. 994). This thesis focuses on semi-autonomous systems, distinct from purely teleoperated and fully autonomous systems.

2.1.4 Relevance and Application of SASRS

As the medical workforce continues to shrink and populations age (Wah, 2025b), SASRS offer a resource solution. They reduce hand tremors, increasing submillimeter accuracy, control, and precision (Olawade et al., 2025; Reddy et al., 2023). Furthermore, variability in individual surgeon skill levels, training, experience, or day-to-day performance is mitigated, enabling more standardized surgical care (Panesar et al., 2019; Saeidi et al., 2022). SASRS also provide surgeons with improved ergonomics (Reddy et al., 2023) and reduce mental fatigue by taking over repetitive tasks (e.g., suturing, camera positioning, or tissue retraction), giving the surgeons the possibility to concentrate on more complex elements of the surgery (Liu et al., 2024; Wah, 2025a).

How far robotic systems are integrated depends mostly on the surgical specialty. *Orthopedics* is the fastest-growing area for surgical robotics (Lee et al., 2024). The TSolution One technology, which autonomously executes bone milling within surgeon-defined virtual boundaries (Iftikhar et al., 2024), is classified as either a Level 2 (Panesar et al., 2019) or a Level 3 robotic system (Lee et al., 2024). *Urology and oncology* have historically pioneered robotic systems adoption, particularly for prostatic procedures (Connor et al., 2020). The AquaBeam system uses ultrasound to map the prostate, and once the surgeon defines the resection boundaries, the robot autonomously performs a heat-free waterjet resection. It is classified as Level 3 autonomy (Connor et al., 2020; Khanna et al., 2025) and is in commercial use. *Neurosurgery* uses the CyberKnife system, which applies real-time imaging and stereotactic principles to track tumor movements and automatically adjust radiation beams. This technology is cited as the most advanced autonomous system in clinical use, classified as Level 3 (Panesar et al., 2019; Saeidi et al., 2022). In conclusion, Level 2 and 3 systems are technically feasible and offer benefits for surgeons and hospitals. This raises the question: What drives routinized adoption?

2.2 Technology Adoption in Hospitals

Human-robot collaboration can be achieved when hospitals and physicians routinely use SASRS. These systems are introduced into a complex sociotechnical environment in which physicians, administrators, regulators, and patients influence whether a technology is adopted or rejected. Adoption operates at different levels, so no single theoretical model can fully explain routinized adoption. This chapter builds on the UTAUT, which captures individual-level factors; the TOE framework, which addresses hospital-level factors; and the DOI model, which explains how adoption transitions into institutionalization.

2.2.1 Technology Acceptance and Innovation Adoption

Technology acceptance research originates with the Technology Acceptance Model (TAM). It frames user acceptance based on perceived usefulness (PU) and perceived ease of use (PEOU) (Davis, 1989). While TAM provides the conceptual foundation, its explanatory power in complex clinical contexts is limited, and the model requires additional factors to capture the social dimensions of adoption (Chau & Hu, 2002; Holden & Karsh, 2010; Lee et al., 2025).

Alternatively, UTAUT identifies four core predictors of adoption: performance expectancy (referring to PU), effort expectancy (referring to PEOU), facilitating conditions, and social influence. Performance expectancy is defined as the extent to which using a technology will improve work performance, and effort expectancy refers to how easy it is perceived to use the technology without significant effort. Social influence relates to leadership or peer norms affecting acceptance, while facilitating conditions reflect the extent to which users believe support and infrastructure exist (Venkatesh et al., 2003). For SASRS, UTAUT forms the demand-side individual perspective of adoption.

To capture the adoption conditions at the hospital level, the TOE framework offers three additional driver categories: 1) technological context, such as relative advantage and compatibility; 2) organizational context, including resources and administrative support; and 3) environmental context, such as competitive pressure and regulations (Tornatzky & Fleischer, 1990). To reach adoption, all three categories must be aligned (Greenhalgh et al., 2017). Together, they build the supply-side of adoption. Thus, even an advanced surgical robot may not be adopted if the hospital lacks the organizational capacity to implement and support it.

2.2.2 Demand- and Supply-Side Determinants

SASRS are complex technologies introduced into a complex sociotechnical system. Multiple factors determine whether or not technology adoption succeeds (Greenhalgh et al., 2017). Drawing on UTAUT and TOE, adoption drivers are distinguished into two high-level dimensions: demand-side factors at the individual level and supply-side factors at the institutional level.

Demand-side factors

At the individual level, surgeons use surgical robots when they believe they improve performance, such as increased precision, reduced hand tremor, and improved ergonomics (Ghaith et al., 2026; Liu et al., 2024; Reddy et al., 2023). However, the cognitive demands of mastering surgical robotics create a barrier due to the learning curve and effort required (Pal, 2024; Zhang et al., 2024). Resistance is further reinforced when semi-autonomy is perceived as a threat to professional identity or clinical autonomy (Greenhalgh et al., 2017). This is because surgeons are concerned about skill erosion, fearing that over-reliance on AI may diminish their manual dexterity and clinical judgment (Taghipour et al., 2025). Yet, peer influence can increase willingness to adopt SASRS (Ghaith et al., 2026; Venkatesh et al., 2003).

Supply-side factors

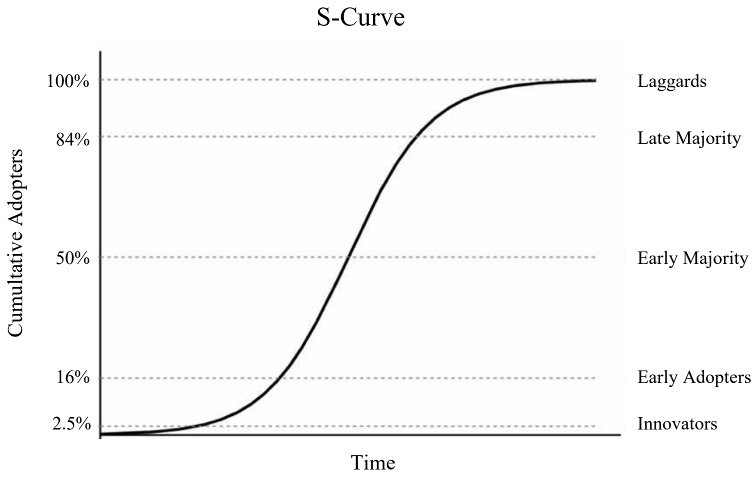
At the institutional level, adoption depends on conditions across all three TOE domains. Technical factors determine whether the system integrates seamlessly into the surgical workflow. Measurable improvements over current standards, such as improved patient outcomes and shorter hospital stays, give a relative advantage and increase adoption potential (Maynou et al., 2024). Adoption is facilitated when the technology aligns with existing digital infrastructure, achieves interoperability, and ensures dependability in routine use (Ghaith et al., 2026; Kok Wah, 2025; Varghese et al., 2024). These characteristics also impact individual-level acceptance, as they can influence performance expectancy, effort expectancy, and confidence in the system (Venkatesh et al., 2003), thereby affecting willingness to adopt. Organizational factors influence whether SASRS can be implemented. Supportive infrastructure and facilitating conditions, such as training and management support, are needed to achieve adoption (Chatterjee et al., 2024; Ghaith et al., 2026). Environmental forces shape the constraints and incentives under which hospitals make adoption decisions. Policies and governance systems influence whether a technology initiative can spread and persist over time. Well-defined rules on data protection, accountability, liability, and reimbursement are essential (Greenhalgh et al., 2017). However, uncertainty surrounding responsibility for AI errors or fatigue during surgery creates a *gray zone* that discourages the use of SASRS (Reddy et al., 2023; Taghipour et al., 2025). Clear governance and rules are needed to reduce uncertainty and increase accountability.

2.2.3 Diffusion of Innovation

To understand technology diffusion from early trials to mainstream practice, the DOI model is used (Rogers, 2003). Individual adoption decisions follow the classic five-phase innovation-decision process (knowledge, persuasion, decision, implementation, and confirmation). How fast an innovation moves through stages depends on five key product attributes (relative advantage, compatibility, complexity, trialability, and observability) and five adopter categories (innovators, early adopters, early majority, late majority, and laggards). The resulting cumulative adoption pattern is expressed as an S-curve, with an inflection point representing the transition to a broader diffusion of the innovation (Rogers, 2003).

Figure 1

S-Curve of the Diffusion of Innovation Process (Own Illustration, Adapted from Rogers, 1983)



Since hospitals adopt technology as complex organizations rather than through individual decisions, Rogers (2003) distinguishes a separate organizational innovation process. It is divided into 1) the initiation phase, in which information is collected, and the decision to adopt is made, and 2) the implementation phase, which is "all events, actions, and decisions involved in putting an innovation into use" (Rogers, 1983, p. 364). The second phase is divided into three sub-stages: a) redefining/restructuring—the need for new organizational structures and routines; b) clarifying—building a clear understanding and wider use of the technology; and c) routinizing—the innovation loses its identity as new, and it becomes an integral part of regular activities. In other words, routinization is the stage where technology use is no longer experienced as novel, but instead becomes embedded as a normalized, institutional element of daily practice (Cooper & Zmud, 1990; Kwon & Zmud, 1987). In consumer goods markets, a decline in prices catalyzes the transition to mainstream use (Moore, 1991). However, in the context of SASRS, acquisition and maintenance costs remain high. Since price is not a key driver, other factors explain routinization.

2.3 Enablers for Routinization

Achieving the transition from initial adoption to routinization requires enabling factors. Initial acceptance is necessary, but not sufficient. While the DOI framework discusses routinization, it does not fully explain how hospitals would achieve institutionalization from within. RBT and DC help to understand routinization and value creation.

2.3.1 From Resource to Value: A RBT Perspective

RBT defines the firm as a distinctive bundle of resources and capabilities oriented towards value creation. This illustrates why some hospitals can implement a technology, while others fail to move beyond procurement. Organizations create value by combining tangible (e.g., personnel, technology, infrastructure) or intangible resources (e.g., know-how, social complexity) (Barney et al., 2021).

In the context of SASRS, resource coordination is critical since the technology creates no value in isolation. Value creation depends on the synergy between physical robotic hardware and specialized infrastructure, such as compatible imaging platforms to support AI functionalities, secure cloud networks, and high-speed computing systems (Arepalli, 2025; Kok Wah, 2025). Available, curated, and annotated datasets are essential to train and refine AI models (Gumbs et al., 2021; Liu et al., 2024). But critical components are the intangible resources. The experience of surgeons and the tacit knowledge embedded in OR routines, including the informal coordination of experienced nurses and technicians, essentially drive value creation (Randell et al., 2017; Varghese et al., 2024). Intangible assets cannot be purchased; they evolve through repeated use.

While SASRS promise long-term benefits (Picozzi et al., 2024), calculating the return on investment beforehand is difficult (Olawade et al., 2025). High upfront acquisition costs and ongoing maintenance fees create substantial financial burdens, further intensified by the lack of long-term clinical evidence and clear reimbursement models (Kok Wah, 2025). The technology's value proposition becomes clearer only through its use, and determining individual resource contributions remains challenging (Barney et al., 2021).

RBT explains the initial resources needed for sustained adoption, but it does not account for the ongoing reconfiguration required. Having the right resources is not enough, since hospitals need the capacity to transform their resource base over time to achieve institutionalization.

2.3.2 Dynamic Capabilities

Building on RBT, DC emphasize that in dynamic environments, firms must transform and reconfigure resources and capabilities over time to respond to rapid changes (Teece, 2007;

Teece et al., 1997). In this study, DC represent the organizational mechanisms necessary to reach the routinizing substage (Rogers, 2003).

DC are defined as a firm's capacity to solve problems in a structured way, identify and interpret emerging opportunities and threats, respond effectively to market changes, and reconfigure its resources and capabilities accordingly (Barreto, 2010).

The dimensions of DC in the context of SASRS are: *sensing*, which recognizes advancing opportunities and threats, such as emerging AI capabilities and the shift from passive tools to active participants capable of independent task execution (Kok Wah, 2025; Saqib et al., 2025); and *seizing,* which entails committing resources to the identified opportunities and threats by making strategic investment decisions (Teece, 2007). While Teece (2007) emphasizes resource commitment, Barreto (2010) places weight on the quality and timing of the decision that leads to the commitment. In surgical robotics, this would include investment prioritization, contracting strategies, and governance designs, as well as mobilizing specialized digital infrastructure (Kok Wah, 2025; Varghese et al., 2024).

The critical dimension for routinization is potentially *transformation*. According to Eisenhardt and Martin (2000), adoption depends on whether a firm has developed specific routines that allow resources to be reallocated under conditions of uncertainty. In the context of this work, this may involve reconfiguring OR workflows, redefining the surgeon's role, and adapting surgical training to new competence requirements (Chatterjee et al., 2024; Keles & Eke, 2025; Khanna et al., 2025; Kok Wah, 2025). Moreover, hospitals must collect, process, and utilize data generated during surgical procedures. They are relevant for AI training and improved feedback loops (Liu et al., 2024; Olawade et al., 2025). This may require restructuring the collaboration between the OR staff and IT units (Greenhalgh et al., 2017).

While DC explain the organizational capacity to reconfigure resources necessary to move to routinization, they do not fully explain the relational dimension of human-machine interaction. Sustained routinization additionally requires trust, which cannot be substituted by organizational capability or governance regulation.

2.3.3 Trust

The surgeon who operates and the patient who undergoes the procedure require trust (Khanna et al., 2025). Regardless of the organizational readiness, it is impossible to use SASRS routinely if trust is absent. Mayer et al. (1995, p. 712) define trust as the "willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that party". This vulnerability is accepted if the trustor believes that the trustee is trustworthy. Originally, this framework was used to explain human-human interaction, but the logic can be transferred to human-machine interaction (Lee & See, 2004). In the context of SASRS, trustworthiness can be evaluated based on three factors introduced by Mayer et al. (1995): 1) ability—robots' technical precision, reliability, and functional performance; 2) benevolence—robots prioritize safety and act in the best interest; and 3) integrity—robots follow rules and accepted principles.

Initial trust is established by preexisting views and beliefs formed by assessing specific features of an object's trustworthiness (Lee & See, 2004). In practice, trust is not static but an ongoing process of trust calibration. In the context of SASRS, miscalibration by the surgeon can lead to either overreliance, potentially leading to patient harm, or under-reliance, which can cause rejection of SASRS ability and the loss of potential benefits (Lee & See, 2004; Mayer et al., 1995).

Trust is essential where AI-supported decisions can trigger semi-autonomous reactions. For surgeons, trust needs to be established through a transparent, traceable, and explainable decision-making process (Knudsen et al., 2024; Kok Wah, 2025). Prior studies investigated patients' trust in robotic surgery and found that trust is not primarily influenced by detailed knowledge about the technology but by the perception of safety, humanistic care, and confidence in the system to handle intraoperative emergencies (Lin et al., 2025). Additionally, patients mistakenly believed that current robotic systems already act autonomously. This makes transparent communication about shared decision-making, capabilities, and the autonomy level (Jauniaux et al., 2025; Khanna et al., 2025) even more important.

2.3.4 Governance and Regulations

To conclude, governance and regulations function as boundary conditions influencing routinization. The transition from an assistive master-slave system to SASRS need modifications in hospital policies and national regulations. This is because SASRS enable shared decision-making. Existing legal and ethical frameworks need to address distributed responsibility, data integrity, and clinical trust (Khanna et al., 2025).

A hurdle arises when SASRS make a decision that results in adverse outcomes, creating legal responsibility. Previously, the surgeon in charge was accountable and liable. With semi-autonomy, decision-making becomes divided, which complicates liability allocation (Olawade et al., 2025). The literature differentiates three layers: 1) accountability refers to the ability to provide reasons and evidence for decisions. As AI becomes more complex, the black-box nature of algorithms makes it more difficult to track decisions (Attanasio et al., 2021; Hashimoto et al., 2018), increasing the need for explainable AI (O'Sullivan et al., 2019); 2) liability refers to civil responsibilities and compensation pathways (Corfmat et al., 2025); and 3) culpability involves the possibility of punishment for criminal negligence (Attanasio et al., 2021). Currently, robots cannot be found guilty as they lack free will or conscience. Thus, culpability remains with the surgeon, software developers, or hospitals that deploy them (O'Sullivan et al., 2019).

Beyond external regulations, hospitals need internal governance to create safe clinical protocols. SASRS adoption requires clear role definitions across the OR team, since automation can increase deskilling and reskilling fears (Khanna et al., 2025).

Ethical governance should entail transparency, explainability, and fairness, emphasizing trust in AI and robotic procedures (Khanna et al., 2025; Kok Wah, 2025). Ethical oversight becomes a core requirement for robot acceptability and legitimacy, since even the best technology is useless if the patient does not trust it (Khanna et al., 2025).

Data governance and cybersecurity also need to be robust, since AI-enabled surgical systems generate and consume large volumes of data (Knudsen et al., 2024). To ensure regulatory compliance and the legitimacy of AI, it is essential to protect sensitive patient data and to maintain system integrity against malware and hacking (Cunha Reis, 2024; Kok Wah, 2025; Olawade et al., 2025; Pal, 2024).

In conclusion, these governance arrangements do not replace organizational capabilities; they enable hospitals to invest in, coordinate, and continuously adapt routines to create sustained clinical value.

2.4 Research Gap

Existing literature focuses predominantly on initial acceptance of AI-enabled surgical tools, rather than routinized adoption. Measuring behavioral intention captures whether clinicians plan to use technology. It does not explain how routinized adoption can be achieved and what organizational capacity is required to sustain its use over time. Recent literature identifies legal liability, lack of governance, and interoperability as roadblocks for surgical robots, but investigations remain largely descriptive and opinion-based.

Existing studies further do not distinguish SASRS from AI-assisted tools. They often combine different autonomy levels under broad labels such as “robotic-assisted surgery”, “AI-enabled surgery”, or “AI-assisted tools”. Finally, the literature focuses primarily on a single-stakeholder perspective, especially centered on surgeons, or in a few cases, patients. Relevant dynamics between stakeholder groups are not considered.

This study seeks to fill the research gap by investigating routinized adoption, not merely acceptance, from the perspective of MedTech experts, physicians, and researchers. Additionally, the patient’s perspective completes the multi-stakeholder analysis.

3 Methodology

The following chapter outlines the mixed-methods approach utilized, combining qualitative and quantitative research.

3.1 Performing Scientific Research

An exploratory sequential mixed-methods design was employed to answer the research question: *What key drivers influence clinical routinized adoption of semi-autonomous surgical robotic systems in hospitals?* The study followed the scientific method by moving from a defined problem and theory-based concepts to systematic data collection, analysis, and evaluation of findings.

The dependent variable was routinized adoption of SASRS, defined as the institutionalization and routine use of SASRS as a normalized element of clinical practice. The independent variables influenced routinized adoption. Key terms were defined to avoid ambiguity and to make measurement decisions transparent.

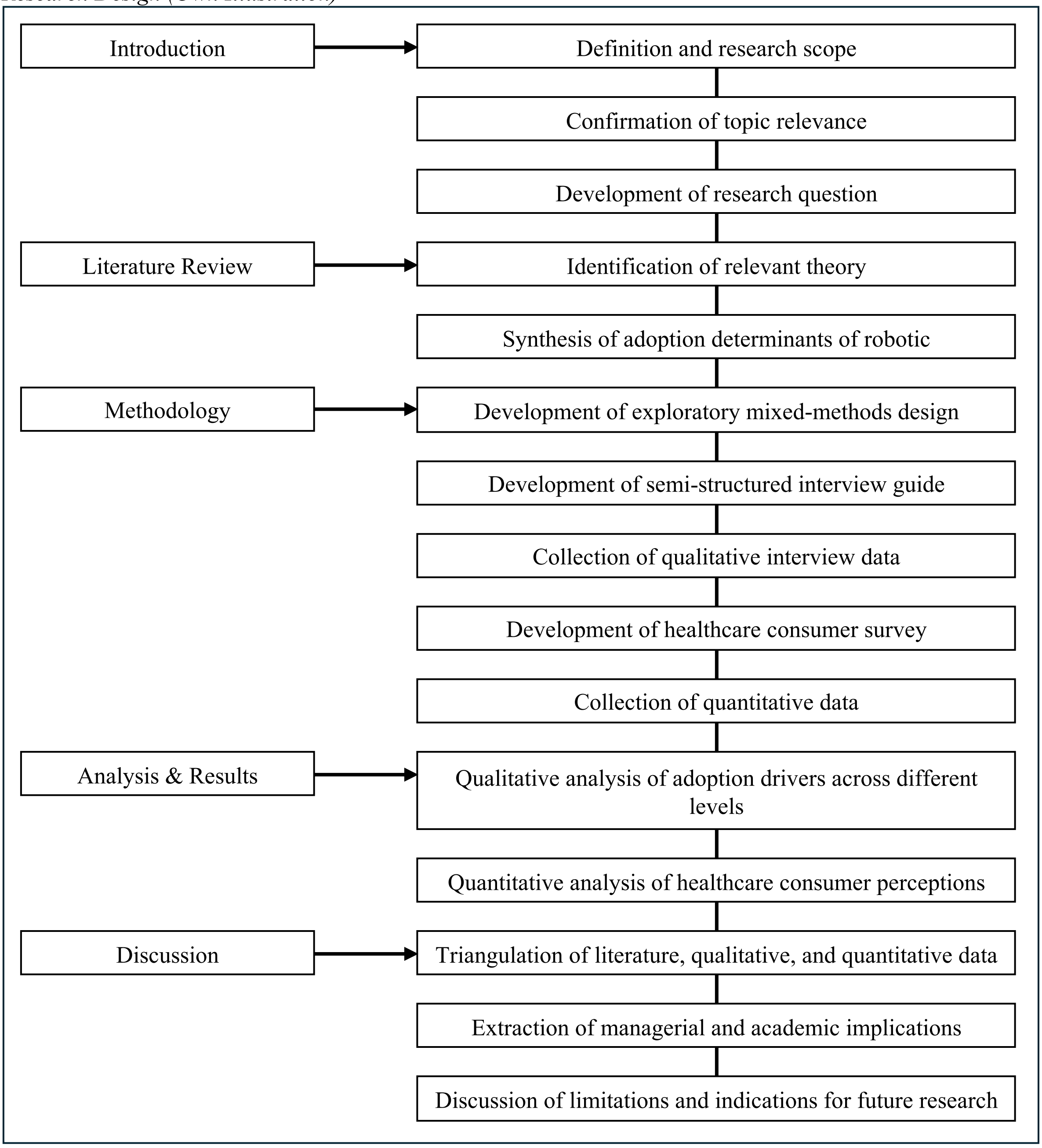
To meet scientific quality criteria, claims were formulated in a way that allowed confirmation or contradiction by evidence. Replicability was ensured by specifying each step and decision rules, allowing other researchers to repeat the study.

The mixed-methods design combined quantitative and qualitative data with inductive and deductive methods to ensure methodological robustness and a deeper understanding of the topic (Creswell & Clark, 2017; Sekaran & Bougie, 2016). Data triangulation enabled comparison and confirmation across secondary and primary evidence sources. This strengthened the credibility, validity, and explanatory power of the results (Creswell & Clark, 2017).

First, a literature review was conducted to gather secondary data, identifying theoretical frameworks and drivers. Additionally, industry experts contributed primary data insights through semi-structured interviews, building on data from the literature review. Subsequently, a quantitative survey tested the public's acceptance of SASRS and assessed statistical significance and generalizability across a larger sample. Together, the three data collection phases provided drivers of routinized adoption of SASRS.

This research acknowledged that triangulation could reduce but not eliminate uncertainty and causal ambiguities by using the strength of one method to compensate for the weakness of another (Yeater et al., 2015). Conclusions should therefore be understood as evidence-based approximations rather than context-free absolutes.

Figure 2
Research Design (Own Illustration)



3.2 Secondary Data Collection Literature Review

A systematic literature review was conducted using PubMed, Web of Science, and Google Scholar. Different keyword combinations and options were tested. The main search terms included “semi-autonomous robotic surgery”, “healthcare”, “adoption”, “hospitals”, “surgical robotics”, “implementation”, “routinization”, and “technology acceptance”. These combinations led to a total of 126 papers identified as relevant for the literature review. A snowballing technique was used to locate additional relevant papers. The inclusion criteria were directed towards assessing whether the title of a paper contained one or more relevant keywords, whether the abstract aligned with the research question, or whether the paper’s results offered insights into the research topic. This led to a total of 78 research papers useful for establishing the research foundation.

3.3 Primary Data Collection Qualitative Study

In total, 15 semi-structured interviews explored experiences, attitudes, and beliefs in a structured way while still leaving room for flexibility to ask follow-up questions based on the ongoing conversation (Rowley, 2012; Turner, 2014). To maintain comparability between participants, interviews were conducted using a guided framework based on knowledge gathered through the literature review (Kvale & Brinkmann, 2009). The theory-driven design integrated constructs from TOE, UTAUT, and managerial theories such as DOI, RBT, and DC.

After the interview guides (Appendix A) were established, the questions were tested with an anonymous participant to ensure proper sequence, wording, and coherence. This ensured neutral, non-leading questioning. Each interview was conducted online in German or English via Teams between March 19, 2026, and April 11, 2026. On average, the interviews lasted 40 minutes.

The 15 interviewees were selected based on their professional background and came from the fields of surgery, engineering, or research related to digital health. The sample included seven MedTech experts, five physicians, and three researchers. Throughout the research, 145 potential candidates were contacted via personal networks, LinkedIn, publications, and email addresses. The sample size ensured data saturation, since additional experts did not add valuable new information. This aligned with empirical studies indicating that data saturation is typically reached within 6–12 interviews (Guest et al., 2006).

Figure 3
Overview of Expert Interview Sample (Own Illustration)

Code	Expert Group	Current Position and Expertise
EI1	MedTech	Diploma engineer with 42 years of experience in medical technology, including clinical settings, hospital planning, and navigation systems. Worked as a manager at a well-known German MedTech company.
EI2	MedTech	AI software engineer with a focus on health-related applications. Projects target clinical record management and patient-facing healthcare solutions.
EI3	MedTech	Engineer and researcher at a well-known MedTech company with a background in medical physics. Specializes in optical coherence tomography and medical robotics, with a focus on sensor data conceptualization for robot-assisted microsurgery.
EI4	Physician	Resident physician at University Hospital Tübingen, Department of Gynecology. Has gained hands-on experience with robot-assisted surgical procedures, particularly the da Vinci system.
EI5	Physician	Operating Room Assistant with over 10 years of experience in surgical settings at a tertiary care university hospital. Specializes in urology and gynecology.
EI6	Physician	Physician and core surgical trainer within the UK surgical training program, specializing in plastic surgery at a nationally recognized pediatric center.
EI7	MedTech / Physician	Professor of radiology at University Medical Center Hamburg and Chief Medical Officer for Europe, the Middle East, and Africa at GE HealthCare, a global MedTech company. Has extensive expertise in positioning AI and semi-autonomous systems for real-world clinical value.
EI8	MedTech	Co-founder of voraus robotic GmbH, former CTO of avateramedical, and former head of the Institute for Mechatronic Systems at Leibniz University Hannover. Focuses on AI-based operating systems for medical robotic applications.
EI9	Researcher	Researcher and surgical simulation trainer at the Department of Pediatric Surgery at LMU Klinikum Munich. Actively involved in surgical research on new techniques and medical devices.
EI10	MedTech	Biomedical engineer and team lead for medical robotics and assistance systems at a well-known MedTech company. Specializes in surgical robotics, soft tissue simulation, and automation for surgical procedures.
EI11	MedTech	Mechatronics engineer and researcher at a major German medical robotics company, specializing in the intersection of AI and robotics. Focuses on assistive functions for surgical robots in ophthalmology, including the autonomous execution of surgical steps.
EI12	Physician	Director of the Department of General, Visceral, Vascular, and Transplantation Surgery at University Hospital Magdeburg. Has practiced robotic surgery since 2013 and leads the hospital's robotic surgery program. Is responsible for the clinical application of and training in robotic surgery at one of Germany's leading university surgical centers.
EI13	Researcher	Surgical robotics researcher specializing in autonomous surgical assistance and hybrid operating room concepts. Has conducted in vivo validation studies on porcine models in collaboration with engineering teams, including studies on autonomous gallbladder retraction. Research focuses on context-aware, semi-autonomous robotic systems.
EI14	Physician	Senior consultant urologist, head of a prostate cancer center, and leader of the junior research group "Intelligent Systems and Robotics in Urology" at the German Cancer Research Center. Focuses on AI applications in operative urology and surgical robotics.
EI15	Researcher	Former chair member of the EU eHealth Network, responsible for interoperability policies and for coordinating European member states on health data. Also serves as professor of digital health at Católica Lisbon.

To ensure the credibility and trustworthiness of the qualitative findings, the components used followed the ethical criteria of Lincoln and Guba (1985):

- Credibility was enhanced through data triangulation (literature, interviews, survey), and direct quotations were used to illustrate findings.
- Transferability was supported by describing the participants' backgrounds and providing detailed contextual descriptions.
- Dependability was achieved by documenting every coding step in an audit trail.
- Confirmability was ensured by interpreting and discussing the information derived from the data.

3.4 Primary Data Collection Quantitative Study

A survey questionnaire was developed by translating themes derived from interviews and concepts from the literature into measurable constructs. The constructs were tested using preexisting, validated items. For the trust indicator, the final scale from Jian et al. (2000) was adjusted and used. To test social influence, the questionnaire from UTAUT was adapted (Venkatesh et al., 2003). Data privacy and security concerns were tested through the IUIPC scale (Malhotra et al., 2004).

The Qualtrics platform was used to design and administer the survey. Questions were formulated in a way that minimized ambiguity and maximized clarity, with respondents evaluating their agreement with 43 statements based on 7-point Likert scales, multiple-choice questions, and true-false questions. Additionally, to ensure unbiased and numerous responses, data was collected anonymously. For ethical and data protection reasons, respondents were informed about the study purpose, data handling, and their opportunity to withdraw at any time. A total of 313 submissions were received by the time the survey closed on April 27, 2026.

3.5 Data Analysis

This section outlines the analytical approach.

3.5.1 Qualitative Data Analysis

The interview data were analyzed using qualitative content analysis according to Mayring (2022). To reduce thematic complexity, a coding system was established to transform statements into coded categories to enable theory-based answers to the research question. Four phases were implemented to ensure transparency and accuracy within the coding process.

First, main categories were deductively formulated from theories in the literature review: UTAUT, TOE, DOI, RBT, DC framework, and Trust Theory as a supplement. Seven main categories were derived: Individual, Technical, Organizational, Environmental, Routinization, Trust, and Governance & Regulations. Each main category was added with meaningful subcategories. In a coding manual, each subcategory included four components: the definition, a positive coding rule, a negative coding rule, and an anchor statement directly extracted from the interview transcripts. To comply with Mayring (2022), three coding units were defined: the interview as the analysis unit, a complete question response as a context unit, and one or several sentences that carry a single substantive idea as the coding unit.

Second, a pilot run with the first interview was done to test the category system, sharpened definitions, and established boundaries between subcategories. Passages that did not fit into the categories but had a meaningful impact were marked and later compared to other transcripts to see if a new inductive category needed to be established. Only one inductive subcategory arose: A5 – Change Resistance, covering individual and cultural reluctance towards new technology that existing categories did not cover. The full coding manual is in Appendix C.1.

Third, all interviews were coded using the finalized deductive and inductive coding system. Each statement was inserted in a structured Excel template with the interview ID, expert group, question block, verbatim quotation, assigned category, and an interpretive memo. In total, 550 direct quotations were categorized. A small section of the Excel is in Appendix C.2. Then the frequencies (Appendix C.3) were counted at three levels:

a) per subcategory across all interviews
b) per expert group
c) by the number and names of interviews in which each subcategory appeared

Fourth, co-occurrence patterns were derived through a quantitative co-occurrence matrix across all 15 expert interviews to determine how often any two subcategories appeared together within the same question block. This produced a 28x28 co-occurrence matrix, recording the raw number of interview segments where pairs occurred. Since raw counting does not indicate whether subcategories are meaningfully connected or merely statistically proximate, a qualitative cluster analysis followed. Each interview was reviewed to identify code combinations within the thematic block. Combinations were included in an Excel sheet with a thematic cluster name, short description, and an illustrative quote. Patterns were then aggregated across all 15 interviews to identify clusters that recurred across experts. After revising the entire category system and labels, it was established that the subcategory D2 and the main category G appeared similar. However, this is not the case since D2 covers regulations as an external macro-level condition shaping the adoption context. In contrast, G covers hospitals' institutional mechanisms and responses as reactions to these regulations.

3.5.2 Quantitative Data Analysis

The 313 submissions received were cleaned before the analysis began in SPSS. To ensure data quality, three pretest submissions were eliminated. One respondent with incorrect answers to the attention-check item and three submissions from participants under 18 years of age were also removed. Furthermore, one respondent with implausible completion times of less than 90 seconds, indicating insufficient attention, was excluded. Since values were measured by a 7-point Likert scale, multiple-choice questions, and true-false questions, no outliers were excluded. The remaining final dataset consisted of 305 valid submissions. Missing data were handled with listwise deletion. 13 cases were excluded due to missing values on the quality orientation item, resulting in a final sample of 292, including this variable. All other analyses were conducted with a full dataset of $N = 305$. Using SPSS, descriptive and analytical statistics were computed.

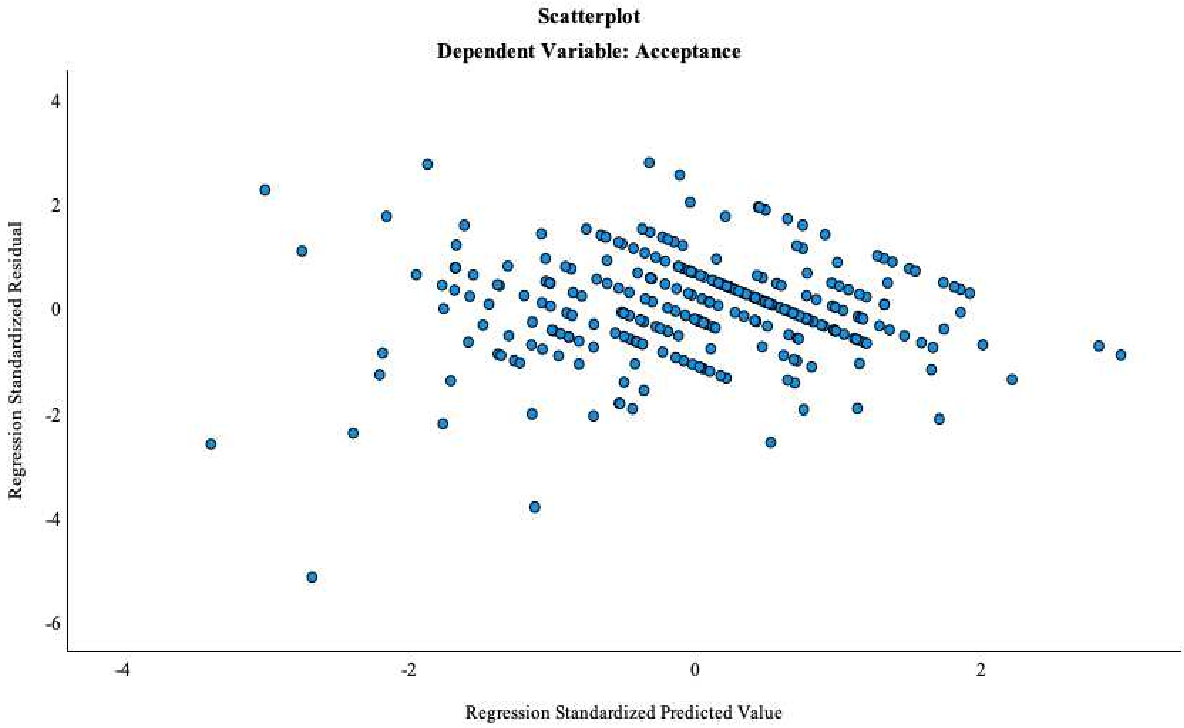
Items measuring the same independent or dependent variable were included in a new variable using a mean calculation. For the independent variable, *prior knowledge*, the correct answers to the multiple-choice questions per submission were added together to create a new variable, as a mean calculation would not have been appropriate. This step was performed in Excel for simplicity. To ensure internal consistency of the constructs, Cronbach's alpha was calculated. Six constructs passed the accepted threshold of $\alpha > .70$, but *peer influence* only reached an α of .638. Therefore, the second item, *"my family and friends support the use of minimal invasive surgery"*, was excluded, as deleting the item would increase Cronbach's alpha to .834 (Appendix E.1).

The control variables were adjusted by creating dummy variables for *gender*, *healthcare insurance statu*s, *perceived healthcare quality*, *surgery experience*, and *healthcare working experience*. With the independent variables and control variables, the dependent variable, *acceptance*, was tested using a multiple linear regression (MLR) analysis. Since the dependent variable is not a simple yes/no question, but rather a range from *strongly disagree* to *strongly agree,* the conversion into a logistic regression would have lost valuable insights.

For the MLR, all assumptions were tested. MLR1 was tested through a curve test performed on the strongest predictor for acceptance, *trust in medical technologies*, which showed that R^2 did not change if the equation type changed from linear to logarithmic or quadratic. MLR2 was fulfilled since it is a random sample, there is no systematic missing data, and no outliers. MLR3 was also fulfilled since all Variance Inflation Factors (VIF) were lower than 5. MLR4 and MLR6 were given due to the large sample size. MLR5 was tested through a residual vs. fitted value plot. This showed a slight structure in the data (Figure 4), which is an indication of heteroskedasticity. To be sure, a Breusch-Pagan test was performed, which showed a violation of homoscedasticity ($p < .05$).

Figure 4

Residual Plot indicating Heteroscedasticity (SPSS Output)



Therefore, HC3 heteroskedasticity-consistent robust standard errors via UNIANOVA procedure were used for the MLR to ensure reliability. It should be noted that SPSS used a different default reference category for the intercept. UNIANOVA uses the highest coded category (category = 1), while normal regression defaults to the lowest coded category (category = 0). As a result, the intercept value and the signs before the dummy categories changed. The strength of the beta stayed the same. The interpretation of the dummy variables shifted, as the reference groups differed between normal regression and the regression with robust standard errors.

4 Results

4.1 Qualitative Results

This section is organized according to the main categories in the category system (A1–G4) established for coding the interviews.

4.1.1 Individual Factors

Individual factors (mentioned 94 times) operated as both drivers and barriers to routinized adoption. Social influence (A3) and performance expectancy (A1) functioned as the primary demand-side drivers, while effort expectancy (A2) and change resistance (A5) were perceived as barriers. Professional identity concerns (A4) emerged as a context-dependent factor based on surgeons' tendencies.

Performance expectancy (A1, 20 mentions, 12 interviews) drove routinized adoption through reduced physical and cognitive workload, as SASRS could take over repetitive tasks. This can "directly impact job satisfaction and may even help prevent burnout" (EI7), making SASRS personally beneficial rather than a mandate.

Effort expectancy (A2, 14 mentions, 10 interviews) represented an early-stage barrier. MedTech and physicians described a steep learning curve where surgeons go through a "valley of despair" (EI7) and a "paradox where initially systems reduce throughput before improving it" (EI6). The perceived complexity threshold for many surgeons is low, as discussed: "If I have to click just once or twice more, I won't use it" (EI7).

Social influence (A3, 23 mentions, 12 interviews) emerged as the strongest driver. University hospitals influenced through publications and conference presentations, "motivating other doctors to try the new method" (EI1). At the physician level, physicians trust physicians (EI5), and "seeing someone else using it is a helpful aspect to using it yourself" (EI6). The bottom-up dynamic through respected colleagues and ambassadors emerged as an important mechanism supporting routinization.

Fear of skill erosion (A4, 19 mentions, 12 interviews) couldn't be uniformly classified: while nine interviews expressed concerns about loss of professional identity and skill erosion, three experts explained that new skills will be acquired (EI6, EI12, EI15). As one physician summarized: “It won’t be the AI that replaces surgeons, rather the surgeons who use AI will replace those who don’t” (EI14).

Change resistance (A5, 18 mentions, 10 interviews) was a structural barrier rooted in a deeply “we’ve always done it that way” (EI5) mindset. Six interviews indicated that age plays a moderating role, as younger surgeons were more open to new technical devices, whereas older surgeons tended to stick to familiar processes.

Across groups, MedTech focused on peer diffusion and initial effort barriers, physicians concentrated on workload and everyday usability, while researchers addressed future disruption of surgical expertise.

4.1.2 Technical Factors

Technical factors (mentioned 52 times) showed that relative advantage (B1) functioned as a strong technical driver, while compatibility (B2) and technical reliability (B3) operated as prerequisites that needed to be met before routinization could begin.

Relative advantage (B1, 29 mentions, 14 interviews), such as stable performance, higher precision, and the standardization of surgical outcomes, motivated routine use. “A surgeon who stands at the operating table for eight hours will eventually lose focus, but the machine works just as well in the first hour as it does in the 25^{th}” (EI1). The possibility of scaling knowledge across the hospital (EI10) and reducing staff shortages by letting robots take over some tasks represented benefits.

Compatibility and interoperability (B2, 12 mentions, 7 interviews) were prerequisites for institutionalization. “Achieving true interoperability with existing systems is difficult and takes time” (EI7). Problems arose when robotic platforms couldn’t easily exchange data with PACS (picture archiving and communication system), electronic health records, or documentation systems, creating isolated islands that complicate workflows instead of simplifying them. If the system remained technically and digitally detached, it hindered routinization since workarounds for transferring data made staff less likely to use robots as a standard option.

Technical reliability and maturity (B3, 11 mentions, 7 interviews) were equally prerequisites. A robotic system that shut down during a surgical procedure was considered “an absolute disaster” (EI5) and immediately eroded trust.

Across groups, MedTech focused on benefits, system architecture, interoperability, and maturity, reflecting a product-launch perspective. Physicians emphasized benefits and interoperability problems, while researchers were most critical of the current technical maturity. Concluding, MedTech saw B2 and B3 as solvable engineering problems, while physicians and researchers treated them as hard prerequisites before trust could even begin to form.

4.1.3 Organizational Factors

Organizational factors represented the most frequently discussed category (mentioned 131 times). The high coding frequency indicated that routinization was primarily an organizational challenge: technology readiness was necessary but insufficient without concurrent resource mobilization, workflow integration, and leadership commitment.

Management support (C1, 15 mentions, 8 interviews) was less a yes/no question of whether to implement and more a question of ownership, stakeholder inclusion, and an innovation mindset. “It’s often unclear who was responsible within the organization for the implementation” (EI7). This limited SASRS from moving beyond pilot projects. Experts indicated that routine use only materialized when management actively steered training, managed resource allocation, and cross-functional coordination between clinical leadership, procurement, and the entire operating team, not only surgeons.

Financial resources (C2, 29 mentions, 14 interviews) were an organizational barrier. High upfront costs combined with maintenance, single-use instruments, training, and licensing fees created a structural access problem: “a system that costs a lot of money but doesn’t generate any revenue will very quickly end up gathering dust” (EI1). Case volume could enable cost recovery and sustained routinized adoption.

Tangible and intangible resources (C3, 57 mentions, all interviews) represented the broader organizational prerequisite. Physical requirements included power supply, dedicated IT infrastructure, reliable consumables, maintenance services, and technical support. Until now, hospitals have lacked in those areas. The shortage of skilled OR staff was a bottleneck that motivated the development of surgical robots (EI3) but also limited the personnel available for training. Training emerged as a critical resource that needed to be in place to reach routinized adoption. "For optimal care, training is essential already in the educational phase" (EI3). Because "robotic surgery is a team effort" (EI12), training must extend beyond surgeons to the full OR team.

Workflow integration and infrastructure (C4, 30 mentions, 12 interviews) acted as a barrier and a prerequisite. The "biggest bottleneck is rarely the technology itself but rather the system in which it is embedded" (EI7). In most hospitals, ORs were too small to facilitate SASRS, limiting their deployment to one or maybe two rooms. This created scheduling bottlenecks, while longer preparation times for setup and sterilization added frictions that discouraged routinized adoption (EI5, EI6).

Across expert groups, MedTech experts focused more on economic feasibility and infrastructure readiness, physicians on staffing, training, and workflow fit, where several noted that scheduling and room constraints prevented routinization. Researchers focused on structural capacities. All groups agreed that technology readiness alone was insufficient; organizational embedding determined whether adoption translated into routine.

4.1.4 Environmental Factors

Environmental factors were described as macro-level conditions that defined the external boundaries, which were outside the hospital's direct control (mentioned 75 times).

Competitive pressure (D1, 24 mentions, 11 interviews) created external adoption motivation to remain attractive for patients and surgeons. SASRS functioned as a "unique selling point attracting more patients" (EI1), and hospitals already positioned themselves as "the center for robotics to show the public we're better than the rest" (EI9). Additionally, hospitals without robotics risked losing surgeons who "wouldn't want to work in a hospital that doesn't have the latest technology" (EI7).

The external regulation context (D2, 33 mentions, 12 interviews) was the dominant structural barrier across interviews. Medical device regulation (MDR) approval was described as "quite a challenge" (EI1), with "incredibly difficult pathways to get anything approved for in vivo use" (EI3).

Reimbursement and funding models (D3, 18 mentions, 11 interviews) were a systematic barrier that constrained routinization regardless of clinical willingness. Within diagnosis-related group (DRG)-based systems, AI functionalities were "rarely compensated for" (EI8), and statutory health insurance structures limited the possibility to "say that people pay more for certain premium surgeries" (EI11). Until reimbursement structures are realigned, the financial viability of routine use remains limited.

Across expert groups, all indicated that external regulations were a huge hurdle that restricted adoption. MedTech focused on market access, regulation, and business models, whereas physicians focused on hospital competition and attractiveness. A key divergence emerged on D3: MedTech framed reimbursement as a business model problem, while physicians experienced it as a clinical constraint. Overall, environmental factors were boundary conditions where D1 motivated adoption, D2 slowed scaling, and D3 determined whether routine use was even economically sustainable.

4.1.5 Routinization

The object of study was to investigate the key drivers that enable routinized adoption of SASRS. Experts placed the current stage of adoption between the innovator and early adopter phases. They defined routinized adoption as the point at which novelty disappeared, and use became common and "a natural part of the process" (EI8). As an expert declared: "Implementation is one thing, but the real work begins after that" (EI7).

To enable routine use, hospitals needed to "continuously adjust purchasing, logistics, scheduling, and staff allocation" (EI1) because a robot "introduces a whole new way of working that needs to be adopted" (EI3). Ongoing standardized training was the central reconfiguration mechanism. "The more complex and sophisticated the equipment is, the more often you simply need to undergo this training" (EI5), and it needed to take the form of "ongoing courses, simulations, and workshops" (EI6). Eight experts mentioned the importance of integrating the entire OR team into the training. With the routine use of SASRS, roles would change, and OR nurses and assistants would take on new tasks. Therefore, DC, through the transformation of workflows, roles, and training, were necessary to reach sustained routine use of SASRS.

Across expert groups, MedTech framed routinization as a scale-up and post-implementation transformation process; physicians and researchers described it through smooth, team-based clinical procedures and structural training. However, all expert groups mentioned that routinized adoption was only reached through transformation and reconfiguration, while sensing and seizing were nearly absent. This might reflect the current maturity stage of SASRS, where hospitals do not actively scan the technical environment or make strategic investment decisions for SASRS.

4.1.6 Trust

"Healthcare is a business of trust" (EI7), and trust functioned as a multi-level enabling condition (mentioned 73 times), spanning from surgeons' trust in the system's ability, predictability, and explainability of decisions to patients' trust in SASRS procedures. As one MedTech expert summarized the causal chain: "first, the surgeon needs to trust the technology; then, the patients trust the surgeons, not the technology. That is the building block to enable routine use" (EI10).

Surgeons' trust in the system's ability (F1, 10 mentions, 6 interviews) marked a prerequisite. "If surgeons don't trust that the robot works properly, then it's all over" (EI3). Trust is built through visible, repeatable clinical outcomes. But this faces a *chicken-and-egg problem*: Large case numbers to generate robust evidence need prior trust and approval, while that trust depends on evidence that does not exist at scale (EI8).

Explainability (F3, 12 mentions, 8 interviews) was a necessary enabling condition. Surgeons needed transparency in how decisions were reached (EI6, EI2, EI14) as a lack of transparency around AI decisions and updates led to skepticism. Real-world data, clear documentation of system limits, and explicit communication of AI decision logic were trust-building necessities.

Patients' trust (F5, 25 mentions, 10 interviews) functioned as the ultimate gatekeeper. Without patients' consent to robotic procedures, no routine use was possible. Experts mentioned that many patients feared "the robot might suddenly start acting on its own" (EI5) or misunderstood who was operating (seven experts). Four experts argued that patients' trust could be built through open communication about task allocation, human oversight, and the surgeon's ability to intervene at any moment.

Trust calibration (F4, 21 mentions, 9 interviews) needed to be actively managed since overreliance was described as a real risk leading to adverse patient outcomes, while under-reliance was identified as a barrier when physicians chose established techniques over robotic methods, even though the outcome would be better.

Across expert groups, MedTech experts addressed trust most comprehensively, reflecting their role as system designers who need to anticipate all failure points. Physicians focused intensively on patients' trust and trust calibration, driven by direct accountability for adverse outcomes.

4.1.7 Governance & Regulation

Governance & Regulations (mentioned 51 times) appeared in the interviews as structural conditions. These were the institutional mechanisms required to make routine use controllable, legally defensible, and safe. The unresolved allocation of responsibility and liability (G2, 12 mentions, 7 interviews) for SASRS errors was described as a fundamental barrier to routinization, especially for physicians and MedTech experts. As long as physicians perceived that they remained fully liable even if the AI made errors, approved medical device status, and extensive training remained strict preconditions. Accountability (G1, 3 mentions, 3 interviews) emerged as an important issue, as experts questioned how AI-supported decisions and actions could be traced, documented, and audited.

Internal clinical governance (G3, 17 mentions, 9 interviews) was mentioned as a concrete enabler that hospitals could use to make routine use controllable and safe. A clear internal responsibility allocation when things go wrong (EI5) was necessary. Seven interviews indicated that hospitals moving towards routinization need to formalize training and procedure standards, such as mandatory pre-use simulation training (EI13), minimum case numbers per surgeon (EI15), and standardized operating procedures (SOP) for workflow and staffing.

Data privacy and cybersecurity (G4, 19 mentions) were seen in eleven interviews as a necessary but restrictive condition, particularly in Germany. Three MedTech experts mentioned that surgical robots collect and process a large amount of sensitive patient data that needs to be handled safely within hospitals. Local servers, encryption, separate networks, and on-device anonymization were communicated as technical and organizational solutions (EI3, EI7, EI8, EI13).

4.1.8 Meta Patterns Across Interviews

The co-occurrence analysis across interviews showed that routinized adoption was not driven by isolated factors but by recurring combinations of drivers, enabling conditions, and structural constraints.

The main driver patterns were the co-occurrence of performance expectancy (A1) and relative advantage (B1), which showed that routinized adoption became more likely when the systems were perceived as clinically beneficial and personally useful. Social influence (A3) frequently appeared together with change resistance (A5) and skill erosion (A4). This indicated that peer influence and ambassadors were necessary to reduce skepticism and spread the diffusion among surgeons.

A second group of meta-patterns reflected the key enabler of routinization: interoperability (B2) and the necessary resources (C3), as well as the relevant workflow integration and infrastructure (C4). In combination with the reconfiguration and transformation (E3), they showed that routinization depended on the continuous adaptation of processes, logistics, staffing, and especially training. It was not a one-time implementation but rather an ongoing process. The combination of explainability (F3) with trust calibration (F4) indicated that transparent system behavior translated directly to the right trust calibration and safe routine use.

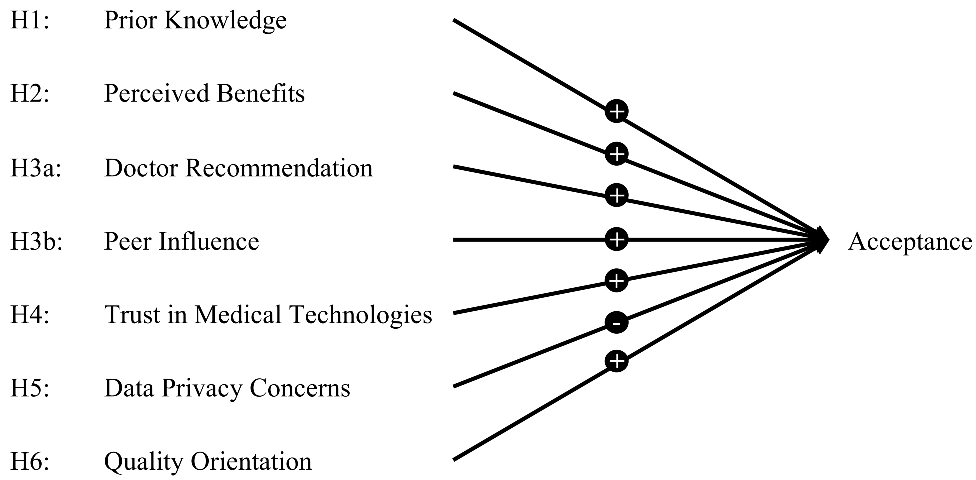
The third group revealed the main boundary condition. Financial resources (C2) together with reimbursement and funding structures (D3) defined the economic feasibility of routinized adoption. External regulatory context (D2), data privacy and cybersecurity (G4), liability allocation (G2), and clinical governance structures (G3) showed the external and internal conditions under which routinization could occur.

Taken together, these co-occurrence patterns showed that routinized adoption emerges only when clinical value, social legitimation, operational embedding, trust formation, organizational support, and institutional feasibility are aligned.

4.2 Quantitative Results

While the expert perspective captured the supply- and demand-side dynamics from an institutional viewpoint, a central prerequisite for routinized adoption was patient acceptance. The survey tested whether patients would accept SASRS and which factors influenced this acceptance. Six hypotheses were tested, which emerged from the interviews and the literature. The dependent variable was *acceptance* since patients accept and consent to undergoing an operation with SASRS and do not adopt it.

Figure 5
Overview of Hypothesis (Own Illustration)

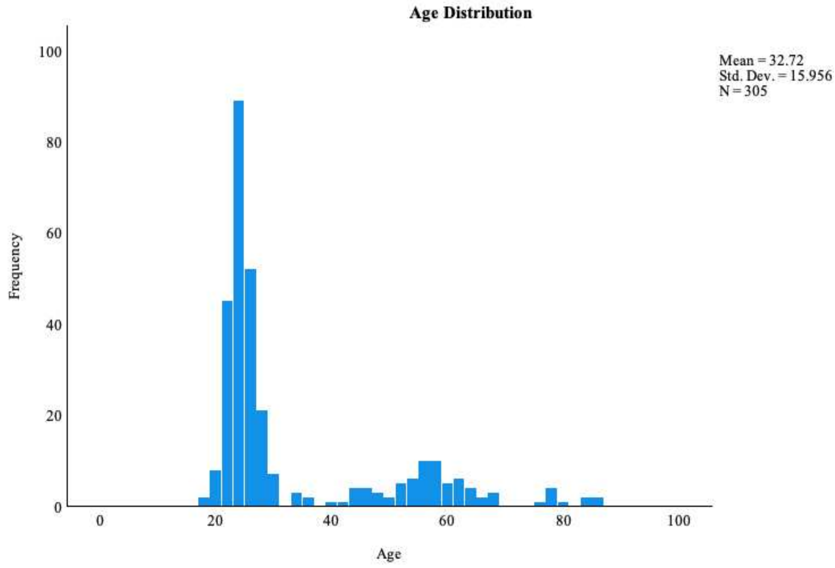


4.2.1 Descriptive Statistics

A total of 305 valid responses were included in the analysis. Of the respondents, 64% identified themselves as female and 35.7% as male. Most participants were from Central and Western Europe. The median age was 35 years, while the mean age was 32.72 years.

Figure 6

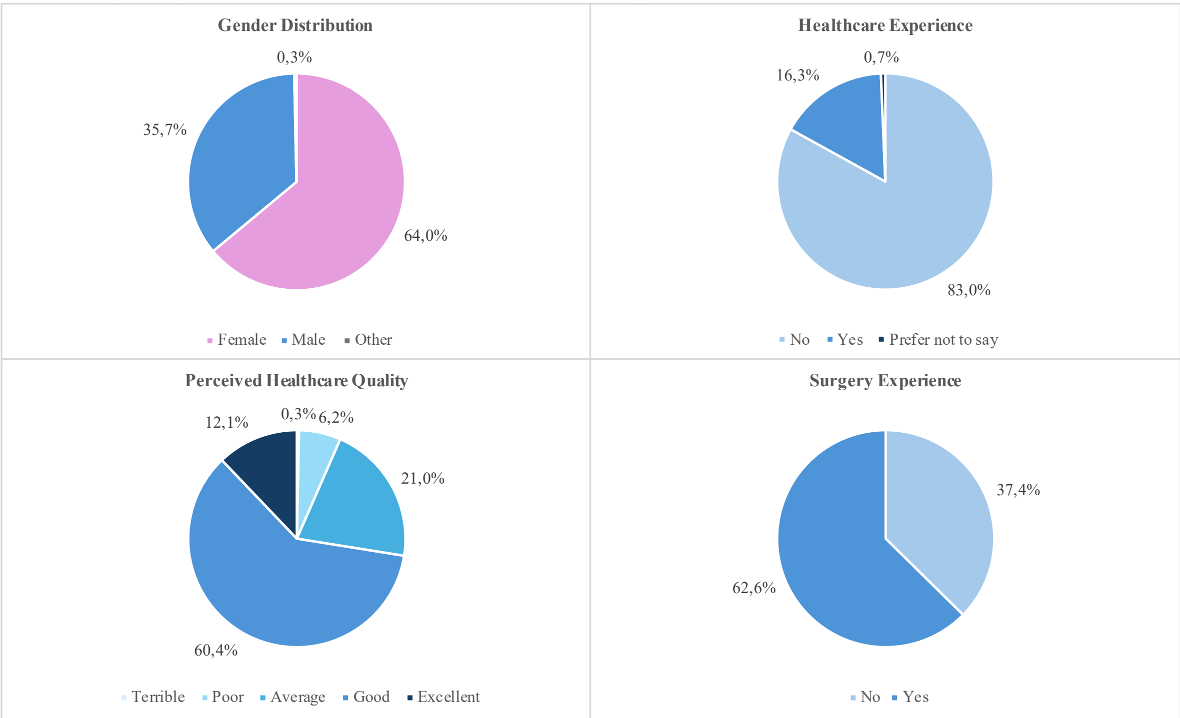
Histogram Age Distribution (SPSS Output)



Furthermore, 62.6% had previously undergone surgery, while only 16.3% currently worked or had worked in the healthcare sector. 60.4% perceived the healthcare system in the country where they currently lived as “good”, followed by “average” at 21%. The highest educational level reported by most participants was a bachelor’s degree (35.7%), followed by a master’s degree (29.8%) and an apprenticeship (14.4%).

Figure 7

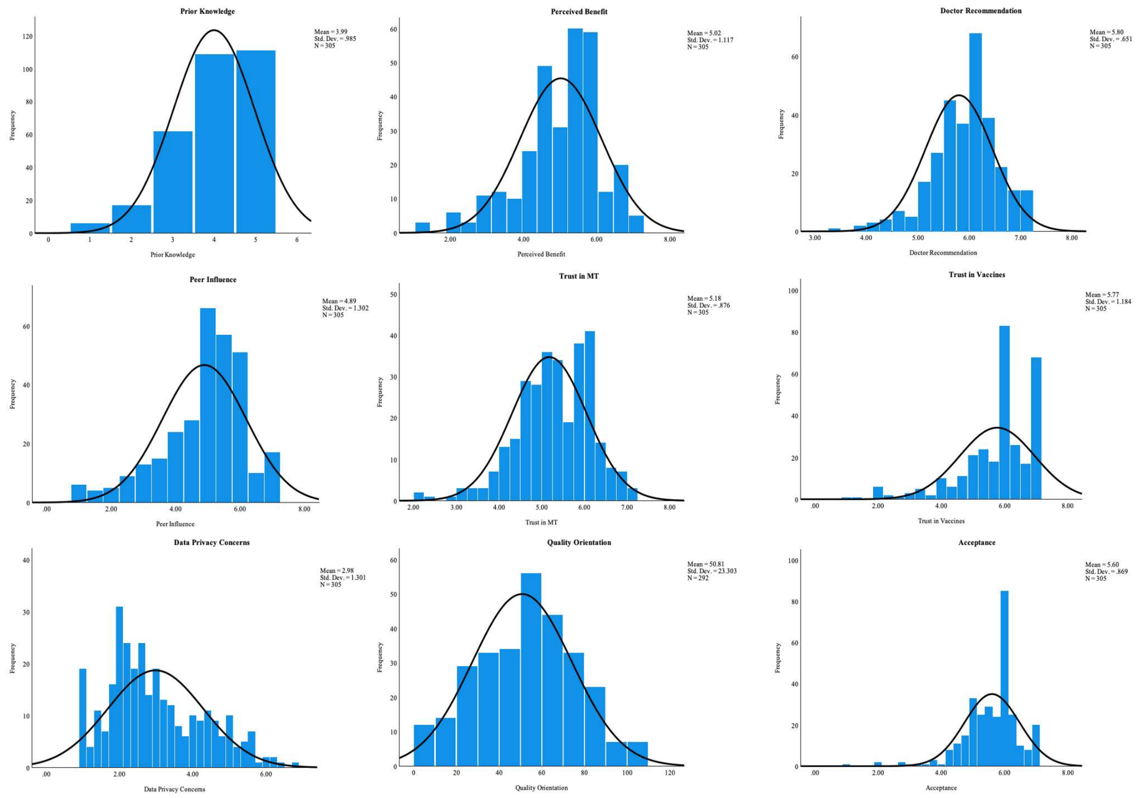
Overview of Sample and Clinical Characteristics (SPSS Output, Own Illustration)



Additionally, all variables were tested for normal distribution to assess whether there were any violations. As shown in Figure 8, all variables were normally distributed.

Figure 8

Overview of Histograms—Normal Distribution (SPSS Output, Own Illustration)



The distribution of the *acceptance* variable (*M* = 5.60, *SD* = 0.869) indicated a strong and consistent positive attitude toward robotic surgery among participants, with the majority of responses clustered near the upper end of the scale. The slight left-skewness of the distribution further confirmed that low acceptance scores were rare, suggesting that SASRS were broadly perceived as a welcome advancement by the surveyed population. Descriptive analyses of all study variables revealed generally positive response tendencies across the sample. All constructs scored above the theoretical midpoint, including *Prior Knowledge* (*M* = 3.39), *Perceived Benefit* (*M* = 5.02), *Trust in Medical Technologies* (*M* = 5.18), *Doctor Recommendation* (*M* = 5.80), *Trust in Vaccines* (*M* = 5.77), and *Acceptance* (*M* = 5.60). *Peer Influence* showed the highest variability (*SD* = 1.302), indicating heterogeneous perceptions of social influence across participants. *Quality Orientation* was assessed on a different scale (0–100; *M* = 50.81, *SD* = 23.303) and was therefore not directly comparable to the remaining Likert-scaled variables.

4.2.2 Inferential Statistics

As mentioned before, a MLR was conducted with *acceptance* of SASRS as the dependent variable. The main predictors were *prior knowledge* (H1), *perceived benefit* (H2), *doctor recommendation* (H3a), *peer influence* (H3b), *trust in MT* (H4), *data privacy conc*erns (H5), and *quality orientation* (H6). First, a normal regression (Model 1—Appendix E.2) was conducted, which showed that the model violated homoscedasticity. Therefore, second, HC3 robust standard errors were used through an UNIANOVA procedure. Given that robust standard errors were methodologically more appropriate under heteroskedasticity, all subsequent interpretations were based on the robust model (Model 2). The results were consistent between the two models, with only one notable exception, which was *prior knowledge* (H1).

Figure 9

Model 2 with Robust Standard Errors predicting SASRS Acceptance (SPSS Output, Own Illustration)

					95% Confidence Interval	
Model 2 (UNIANOVA)	B	Robust Std. Error[a]	t	Sig.	Lower Bound	Upper Bound
Intercept	1,281	0,594	2,155	0,032	0,111	2,451
Quality Orientation	0,002	0,002	1,115	0,266	-0,001	0,005
Prior Knowledge	0,084	0,045	1,877	0,062	-0,004	0,172
Perceived Benefit	0,214	0,041	5,185	0,000	0,133	0,295
Doctor Recommendation	0,272	0,093	2,932	0,004	0,089	0,454
Peer Influence	0,024	0,038	0,631	0,528	-0,051	0,100
Trust in MT	0,320	0,074	4,323	0,000	0,174	0,466
Trust in Vaccines	0,036	0,033	1,106	0,270	-0,028	0,101
Data Privacy Concerns	-0,097	0,035	-2,759	0,006	-0,166	-0,028
Perceived Healthcare Quality	-0,063	0,055	-1,159	0,247	-0,170	0,044
Age	-0,003	0,004	-0,969	0,333	-0,011	0,004
Gender = female	-0,044	0,075	-0,585	0,559	-0,191	0,103
Healthcare Experience = no	-0,102	0,113	-0,902	0,368	-0,324	0,121
Surgery Experience = no	-0,169	0,077	-2,214	0,028	-0,320	-0,019
Additional Private Coverage = no	-0,023	0,081	-0,286	0,775	-0,182	0,136
Private Health Insurance = no	0,124	0,117	1,058	0,291	-0,107	0,355

a. HC3 method

Dependent Variable: Acceptance

R Square	Adjusted R Square
0,568	0,544

Note. N = 292. Parameter estimates from a univariate analysis of variance (UNIANOVA) with HC3 robust standard errors. The dependent variable is acceptance. 95% confidence intervals are reported, and *p*-values < .05 indicated statistical significance.

The overall model explained 56.8% of the variance in acceptance (R^2 = .568, adjusted R^2 = .544), indicating a moderate model fit. H1 proposed that the higher a patient's prior knowledge of SASRS, the higher the acceptance of SASRS. While in Model 1 the predictor was statistically significant (B = 0.084, p = .023), under robust standard errors (Model 2), this was no longer true (B = 0.084, p = .062). Therefore, prior knowledge did not significantly predict acceptance.

H2 stated that the higher a patient's perceived clinical benefit of SASRS, the higher the acceptance of SASRS. The effect of perceived benefit was positive and statistically significant (B = 0.214, p < .001). Therefore, H2 was strongly supported.

H3a proposed that stronger social influence via a doctor's recommendation increases acceptance. The hypothesis was statistically significant and supported with a positive beta (*B* = 0.272, *p* = .004). This indicated that a one-unit increase on the 7-point Likert Scale of doctor recommendation increased acceptance by 0.272.

H3b predicted that the higher the social influence through family and friends, the higher the acceptance of SASRS. Even though the effect was positive, it was not statistically significant (*B* = 0.024, *p* = .528). This indicated that peer influence did not significantly predict acceptance, but doctor recommendations did.

H4 stated that the higher a patient's trust in new medical technologies, the higher the acceptance of SASRS. The effect was statistically significant, positive, and the strongest in the analysis (*B* = 0.320, *p* < .001). Therefore, trust in new MT was the strongest positive predictor of SASRS acceptance.

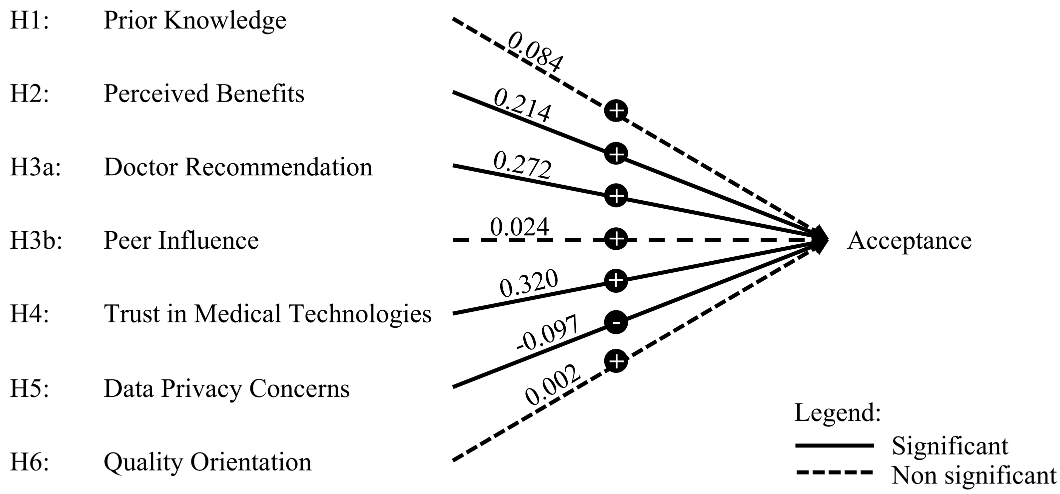
H5 proposed that the higher a patient's concern about privacy and data security in the context of SASRS, the lower the acceptance of SASRS. The effect was statistically significant and negative (*B* = -0.097, *p* = .006). Therefore, privacy concerns negatively affected acceptance.

H6 stated that the higher the use of SASRS is perceived as being driven by quality improvement rather than cost reduction, the higher the acceptance of SASRS. This effect was very small and non-significant (*B* = 0.002, *p* = .266).

The control variables *age*, *gender*, *healthcare experie*nce, *perceived healthcare quality*, and *insurance status* did not have any significant effect on acceptance in either model. Only the dummy control variable *surgery experience* showed a significantly negative effect (*B* = -0.169, *p* = .028). This indicated that if a person had no prior surgery experience, compared to a person who had, the acceptance decreased by -0.169. In conclusion, the acceptance of SASRS by patients is mainly positively driven by trust in MT, doctor recommendation, perceived benefits, and is negatively influenced by data privacy concerns and no prior surgery experience.

Figure 10

Effect Size and Statistical Significance of Hypothesis (Own Illustration)



4.2.3 Additional Findings

As an additional exploratory analysis, a paired-samples t-test was conducted to compare patients' trust in MT with their trust in vaccines. The results indicated that participants reported higher trust in vaccines (M = 5.77) than in MT (M = 5.18). This effect was also statistically significant ($t(304) = -8.570$, $p < .001$). The effect size was medium (Cohen's d = -0.491; Hedges' g = -0.490), indicating a meaningful difference. The moderate positive correlation between the two trust variables (r = .349, $p < .001$) suggested that participants who trusted vaccines also tended to trust MT. Overall, the test indicated that trust in vaccines was significantly higher than trust in MT. All statistical values can be found in Appendix E.4.

Figure 11

Overview Paired Samples t-Test of Trust in Vaccines vs. Trust in MT (SPSS Output, Own Illustration)

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Trust in MT - Trust in Vaccines	-0,58989	1,20212	0,06883	-0,72534	-0,45444	-8,570	304	0,000

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Trust in MT	5,1773	305	0,87570	0,05014
	Trust in Vaccines	5,7672	305	1,18381	0,06778

5 Discussion

The interviews directly measured routinized adoption, while the survey focused on acceptance, since patients do not adopt the technology, but consent to a SASRS procedure. Both constructs existed in a state of structural dependency: Without patient consent, no procedural volume is generated; without volume, no clinical evidence or tacit knowledge is developed, which are needed for routinization. The DOI theory described routinization as the point where the technology loses its identity as new and becomes an integral and normalized element of daily practice (Cooper & Zmud, 1990; Kwon & Zmud, 1987; Rogers, 1983). This was replicated throughout the interviews, which defined routinized adoption as the point where novelty disappeared, no more explanations were needed, and it became a natural part of the work. Therefore, all the factors discussed are drivers for establishing SASRS as a normalized and natural element of surgical procedures.

5.1 Main Findings

The following subsections discuss the empirical findings and examine whether they align, extend, or challenge existing literature.

5.1.1 Individual Drivers as a Routinized Adoption Mechanism

UTAUT predicts individual acceptance through performance expectancy, effort expectancy, facilitating conditions, and social influence (Venkatesh et al., 2003). Consistent with the findings, the interviews showed that expected benefits for surgeons drove adoption since reduced physical and cognitive workload was perceived to increase job satisfaction. As already mentioned in the literature, peer influence through colleagues can drive adoption of SASRS (Ghaith et al., 2026; Venkatesh et al., 2003). This was confirmed by the experts, who mentioned that it was the primary diffusion mechanism. Opinion leaders, ambassador programs, and conferences are therefore effective mechanisms to reach SASRS routinization. The patients' survey sharpened this finding. While doctor recommendations significantly predicted acceptance, peer influence did not, suggesting that patients rely more on professional authority figures than on informal peer networks. This finding extends UTAUT's general social influence construct by identifying a domain-specific boundary condition absent from the original framework.

Interviews revealed hospitals' resistance to change, effort expectancy, and a mixed expert view of skill erosion as barriers. While some acknowledged the fear of skill erosion, others saw the opportunity to acquire new skills. Literature confirmed concerns about skill erosion (Taghipour et al., 2025) and the divide between early and late adopters (Rogers, 1983). While it was mentioned as a barrier, social influence through colleagues can overcome these concerns by providing a relative counter-narrative. Effort expectancy, resulting in a steep learning curve, established a barrier mentioned by experts, which was confirmed through the literature (Pal, 2024; Zhang et al., 2024).

5.1.2 Patients' Acceptance as Prerequisite

Patients' acceptance appears to function as a structural prerequisite for routinized adoption. A notable divergence emerged regarding patient misconceptions. Both the literature and interviews identified patients' misunderstandings about SASRS capabilities (Jauniaux et al., 2025; Khanna et al., 2025), but survey participants demonstrated no such misconception, as measured by prior knowledge. The strongest predictor of patient acceptance was trust in MT. The interviews revealed that patients' trust can be built through open communication and explanation, which was also emphasized by the literature, with an additional emphasis that the perception of humanistic care and safety is important (Jauniaux et al., 2025; Lin et al., 2025). Patients without surgical experience showed lower acceptance of SASRS, lacking a surgical reference point, which may generate abstract skepticism. This makes experienced patients a more accessible early adopter population. Therefore, patients' acceptance is a prerequisite for SASRS routinization, since no procedure can take place without their consent.

5.1.3 Trust as a Multi-Level Enabling Condition

Trust emerged as a cross-cutting enabling condition, operating simultaneously at the patient, surgeon, and institutional level. In the literature, trust was theoretically grounded through ability, benevolence, and integrity (Mayer et al., 1995). Trust calibration added a further complexity layer: both overreliance and under-reliance represented failure modes with direct patient safety implications (Lee & See, 2004; Mayer et al., 1995). Empirically, trust proved to be the strongest predictor of patients' SASRS acceptance, making it a prerequisite for any routine use. At the surgeon level, experts expressed trust in the system's capabilities and the traceability of its decision-making as essential. Without trust, surgeons either avoid the technology or delegate too much to SASRS, risking harmful outcomes through overreliance.

5.1.4 Technical Drivers as a Routinized Adoption Opportunity

The literature identified three key drivers: relative advantage over existing technologies, seamless integration into existing infrastructure, and technical readiness (Ghaith et al., 2026; Kok Wah, 2025; Maynou et al., 2024; Varghese et al., 2024). Interviews confirmed the findings and revealed that relative advantages, such as standardization of care, decreased complication rates, and faster patient recovery, drive SASRS routinization. This finding was complemented by the survey, where perceived patient benefits significantly increased acceptance, indirectly supporting procedural consent and volume generation. Experts emphasized the importance of ensuring interoperability and technical reliability before implementation. Immature and incompatible systems are unlikely to be procured in the first place, making compatibility and maturity enablers for adoption, while relative advantage drives routinization.

5.1.5 Organizational Drivers as a Necessity

Organizational factors were the dominant qualitative empirical category, confirming that routinized adoption is fundamentally an organizational challenge. Tangible and intangible resources, transformation and reconfiguration, and workflow integration were the most mentioned subcategories during the interviews, validating the combined view from the literature review of RBT and the DC framework (Barney et al., 2021; Barreto, 2010). Having the right resources, such as maintenance service, a dedicated IT infrastructure, technical support, and available room space, is not enough. What truly drives routinization is an ongoing transformation. Hospitals that continuously reconfigure workflows, redefine surgical roles, restructure IT-OR collaboration, and importantly have an ongoing standardized training system that integrates the whole OR team can convert SASRS implementation into routine use.

Training emerged as the most important driver. Without structured, team-wide training programs, the OR team lacks safety, trust, and operational efficiency, making training the connective element between resource acquisition and routinized use. Experts further identified management support, clear SOPs, and internal governance structures as active control mechanisms that can make routinized adoption possible, controllable, and auditable.

Accountability and liability allocation were mentioned as unresolved barriers hindering SASRS adoption. Experts consistently raised questions of who bears responsibility when SASRS cause adverse outcomes. This was aligned with the literature on complex liability allocation (Olawade et al., 2025). Financial resources represented a barrier mentioned by experts. SASRS require a high investment with uncertain ROI (Chatterjee et al., 2024), creating procurement hesitance, particularly in public hospitals. As organizational factors could not be measured in the survey, this reveals a triangulation gap.

5.1.6 Environmental and Regulatory Drivers as Boundary Conditions

Environmental factors were described by the literature and the interviews as boundary conditions and constraints under which hospitals make decisions. The literature focused on policies and governance, reimbursement structures, and liability allocation in cases of errors (Greenhalgh et al., 2017; Reddy et al., 2023). During the interviews, competitive pressure emerged as the only environmental adoption driver. Experts described SASRS as competitive differentiators, attracting technology-affine surgeons and patients, creating a certain pull mechanism that can overcome internal resource hesitancy, as already seen with the da Vinci technology. Moreover, experts described EU MDR compliance pathways as slow, costly, and disproportionately burdensome, making external regulation a significant barrier. On the other side, it also created legitimacy, making regulations not inherently harmful, but poorly calibrated. A well-calibrated framework is itself a driver for routinization. Reimbursement models were an additional barrier, since hospitals cannot recover investment costs through standard DRG billing structures. Experts stated that without reimbursement, the financial viability of SASRS are questionable, even with clinical, organizational, and individual readiness. Cybersecurity and data privacy need to be assured, but currently form a barrier, as mentioned by the experts. The survey revealed that data privacy concerns significantly negatively impacted patients' SASRS acceptance. This increases the need for data protection to gain patients' acceptance and perform SASRS procedures.

5.2 Synthesis and Conclusion

This thesis answers the question: *What key drivers influence clinical routinized adoption of semi-autonomous surgical robotic systems in hospitals?* Across all empirical components, routinized adoption of SASRS in hospitals is driven by the dynamic interaction of individual, technical, organizational, environmental, and trust-related conditions, none of which is sufficient in isolation.

The evidence shows that organizational factors constitute the dominant empirical category. Workflow reconfiguration, team-wide training programs, management support, and internal governance structures are what separate implementation from routine use. Having the right tangible resources, such as maintenance services, IT infrastructure, and OR space, is a necessary condition. What drives routinization is an ongoing organizational transformation. Hospitals that continuously reconfigure roles, restructure IT-OR collaboration, and sustain standardized training for the full OR team can convert SASRS procurement into routinized adoption. Training is the critical connective driver—without it, the surgical team lacks the trust, safety, and operational efficiency required for routinized adoption.

Technical factors establish the adoption opportunity that organizational capabilities then activate. Relative advantage functions as the primary driver. Interoperability and technical reliability act as conditions, as systems that are immature or incompatible with existing infrastructure are unlikely to be procured. This makes technical readiness a prerequisite rather than a differentiating driver.

At the individual level, performance expectancy and peer-driven social influence emerge as the primary adoption mechanisms among surgeons. Opinion leaders, ambassador programs, and conferences are the dominant diffusion pathways since social influence operates through professional networks rather than top-down mandates. Change resistance, fear of skill erosion, and high effort expectancies need to be overcome before surgeons are willing to adopt SASRS in their procedures.

Trust operates as a cross-cutting enabling condition that runs through the entire adoption structure. Surgeons need to trust the ability and explainability, while patients' acceptance is most strongly predicted by trust in MT. Without trust, no tier of the adoption structure functions: Patients do not consent, surgeons do not engage, and hospitals cannot establish legitimacy.

Patients' acceptance is a prerequisite for routinized adoption. Without patients' consent, no procedural volume is generated; without volume, neither clinical nor tacit knowledge can be accumulated, creating a chicken-and-egg problem.

Environmental and regulatory factors function as boundary conditions. Competitive pressure drives adoption, while complex EU MDR pathways, unresolved liability allocation, inadequate DRG reimbursement structures, and data privacy concerns need to be overcome to reach adoption.

Taken together, these factors do not determine routinized adoption independently but form a sequential and conditional logic: patient acceptance establishes the procedural base without which no volume, evidence, or tacit knowledge can accumulate; individual factors determine whether surgeons engage; technical maturity and relative advantage shape the credibility of the adoption opportunity; organizational capabilities determine whether a hospital can translate procurement into routine use; and environmental conditions set the boundary within which all of this is financially and regulatorily viable. Trust does not belong to any single dimension—it enables or blocks each transition point across the entire structure. Routinization materializes only when all five dimensions are co-aligned.

5.3 Theoretical and Practical Implications

5.3.1 Theoretical Implications

This study makes three contributions to the existing literature. First, it integrated UTAUT, TOE, RBT, DC, and trust theory into a unified model of routinized SASRS adoption. Previous studies applied those theories in isolation or in partial combination. This thesis demonstrates that each framework is individually not enough and that only the combination of factors explains the pathway to routinized adoption.

Second, it identifies a domain-specific boundary condition within UTAUT's social influence construct. In the model, social influence operates through peer networks. The patient survey revealed that in the SASRS context, patients follow professional authority figures rather than informal peer influence. This finding extends the UTAUT model, contributing to the ongoing refinement of acceptance theory in clinical contexts.

Third, this study repositions patient acceptance as a structural antecedent to routinized adoption, since without consent, no volume is generated; without volume, no routinization can occur. This has direct implications for how future studies should model the adoption pathways.

5.3.2 Practical Implications

For hospital management, routinization requires a sustained organizational commitment. This involves team-wide training programs that include the entire OR team, clear SOPs, workflow integration, a defined accountability structure, and active management support. Trust must be built through transparent communication with patients and a traceable system behavior for surgeons. Hospitals that treat SASRS as an investment rather than an organizational transformation program will not achieve routine use.

For the MedTech industry, relative advantage and technical reliability are necessary but insufficient for market penetration. Industry actors should invest in surgical ambassador programs and peer diffusion networks to accelerate adoption at the individual level. Additionally, data privacy-by-design and improving systems' explainability will directly reduce these two consequential barriers identified in this study.

For policymakers and regulators, the current EU MDR compliance pathway was consistently described as disproportionately burdensome, creating delays in market entry for new technologies. Furthermore, under current DRG billing models, hospitals cannot recover investment costs, leading to SASRS not being economically viable. Therefore, dedicated reimbursement structures and regulatory frameworks are needed as preconditions to be able to implement such technology.

5.4 Research Limitation

This study used a sequential mixed-methods design to investigate key drivers of the routinized adoption of SASRS. While data triangulation increased credibility and explanatory power, several limitations need to be mentioned across the interviews and the survey.

5.4.1 Expert Interviews

While data saturation was reached, the recruitment approach risks a self-selection bias, since the experts already work in digitally mature environments. Individuals with higher familiarity with SASRS were more likely to participate, potentially skewing the results towards more extreme opinions. Thirteen experts were from Germany, and given the regulatory framework and institutional healthcare structure, the transferability of findings to non-German or lower-resource healthcare systems is limited. The qualitative content analysis was conducted by a single coder. Therefore, the coding system and coding decisions remain subject to one coder, which may affect the replicability of the categorical assignments.

5.4.2 Survey

The survey participants were mostly female, based in Germany, and had higher educational backgrounds. These demographic characteristics limit the generalizability of the findings to the broader population. The violation of homoscedasticity represents a potential constraint on the precision of the reported standard errors. Although robust standard errors were applied to address the issue, the underlying causes were not further investigated. The survey used established scales but also included self-developed items. Therefore, the Cronbach's alpha for peer influence was below .70, leading to the deletion of one item to pass the threshold. Additionally, the survey did not test for mediators or moderators affecting routinized adoption, which could add valuable insights.

5.5 Recommendations for Future Research

Building on the limitations of this study, several directions for future research are proposed. Future research should interview a broader range of experts, not limited to those from digitally mature institutions in Germany, thereby capturing the full sociotechnical complexity of adoption. Empirically, longitudinal study designs would be valuable, as routinization is an inherently dynamic process and SASRS are not yet commonly integrated into hospitals. The underlying drivers may shift over time, which cannot be captured in a cross-sectional design. Research that focuses on a specific surgical specialty would allow greater analytical precision, as adoption trajectories likely differ across disciplines. Future quantitative work should also focus on measuring mediators and moderators. Additionally, studies focusing on different regions could reveal differences between, for example, Asia, Europe, America, and Africa. From a policy perspective, future research should evaluate the effects of emerging governance frameworks (eg., EU AI Act) or develop evidence-based reimbursement models.

References

Arepalli, B. R. (2025). Leveraging AI and Machine Learning in Embedded Technology for Healthcare Innovation. *International Journal of Health Sciences*, *8*(1), 31–40. https://doi.org/10.47941/ijhs.2481

Attanasio, A., Scaglioni, B., De Momi, E., Fiorini, P., & Valdastri, P. (2021). Autonomy in Surgical Robotics. *Annual Review of Control, Robotics, and Autonomous Systems*, *4*(1), 651–679. https://doi.org/10.1146/annurev-control-062420-090543

Barney, J. B., Ketchen, D. J., & Wright, M. (2021). Resource-Based Theory and the Value Creation Framework. *Journal of Management*, *47*(7), 1936–1955. https://doi.org/10.1177/01492063211021655

Barreto, I. (2010). Dynamic Capabilities: A Review of Past Research and an Agenda for the Future. *Journal of Management*, *36*(1), 256–280. https://doi.org/10.1177/0149206309350776

Biswas, P., Sikander, S., & Kulkarni, P. (2023). Recent advances in robot-assisted surgical systems. *Biomedical Engineering Advances*, *6*, 100109. https://doi.org/10.1016/j.bea.2023.100109

Cao, H. X., Nguyen, V. D., Park, J.-O., Choi, E., & Kang, B. (2024). Acoustic Actuators for the Manipulation of Micro/Nanorobots: State-of-the-Art and Future Outlooks. *Micromachines*, *15*(2), 186. https://doi.org/10.3390/mi15020186

Chatterjee, S., Das, S., Ganguly, K., & Mandal, D. (2024). Advancements in robotic surgery: Innovations, challenges and future prospects. *Journal of Robotic Surgery*, *18*(1), 28. https://doi.org/10.1007/s11701-023-01801-w

Chau, P. Y. K., & Hu, P. J.-H. (2002). Investigating healthcare professionals' decisions to accept telemedicine technology: An empirical test of competing theories. *Information & Management*, *39*(4), 297–311.

Connor, M. J., Dasgupta, P., Ahmed, H. U., & Raza, A. (2020). Autonomous surgery in the era of robotic urology: Friend or foe of the future surgeon? *Nature Reviews Urology*, *17*(11), 643–649. https://doi.org/10.1038/s41585-020-0375-z

Cooper, R. B., & Zmud, R. W. (1990). Information Technology Implementation Research: A Technological Diffusion Approach. *Management Science*, *36*(2), 123–139. https://doi.org/10.1287/mnsc.36.2.123

Corfmat, M., Martineau, J. T., & Régis, C. (2025). High-reward, high-risk technologies? An ethical and legal account of AI development in healthcare. *BMC Medical Ethics*, *26*(1), 4. https://doi.org/10.1186/s12910-024-01158-1

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage publications.

Cunha Reis, T. (2024). The roadblocks to AI adoption in surgery: Data, real-time applications and ethics. *Medicine Advances*, *2*(4), 380–383. https://doi.org/10.1002/med4.82

Dachs, B., Fu, X., & Jäger, A. (2022). The Diffusion of Industrial Robots. In *The Routledge Handbook of Smart Technologies*. Routledge.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340. https://doi.org/10.2307/249008

Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic Capabilities: What Are They? *Strategic Management Journal*, *21*(10–11), 1105–1121. https://doi.org/10.1002/1097-0266(200010/11)21:10/11<3C1105::AID-SMJ133>3E3.0.CO;2-E

Fiorini, P., Goldberg, K. Y., Liu, Y., & Taylor, R. H. (2022). Concepts and Trends in Autonomy for Robot-Assisted Surgery. *Proceedings of the IEEE*, *110*(7), 993–1011. https://doi.org/10.1109/JPROC.2022.3176828

Fortune Business Insights. (2026). *Robotic Surgical Procedures Market Size, Share & Growth | Report, 2034*. https://www.fortunebusinessinsights.com/industry-reports/robotic-surgical-procedures-market-100124

George, E. I., Brand, T. C., LaPorta, A., Marescaux, J., & Satava, R. M. (2018). Origins of Robotic Surgery: From Skepticism to Standard of Care. *JSLS : Journal of the Society of Laparoendoscopic Surgeons*, *22*(4), e2018.00039. https://doi.org/10.4293/JSLS.2018.00039

Ghaith, A., Alshirbini, M., & Ma, H. (2026). Understanding surgeon adoption of artificial intelligence surgical technology: Integrating UTAUT-TOE model. *Journal of Robotic Surgery*, *20*(1), 135. https://doi.org/10.1007/s11701-025-03116-4

Greenhalgh, T., Wherton, J., Papoutsi, C., Lynch, J., Hughes, G., A'Court, C., Hinder, S., Fahy, N., Procter, R., & Shaw, S. (2017). Beyond Adoption: A New Framework for Theorizing and Evaluating Nonadoption, Abandonment, and Challenges to the Scale-Up, Spread, and Sustainability of Health and Care Technologies. *Journal of Medical Internet Research*, *19*(11), e367. https://doi.org/10.2196/jmir.8775

Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. *Field Methods*, *18*(1), 59–82. https://doi.org/10.1177/1525822X05279903

Gumbs, A. A., Frigerio, I., Spolverato, G., Croner, R., Illanes, A., Chouillard, E., & Elyan, E. (2021). Artificial Intelligence Surgery: How Do We Get to Autonomous Actions in Surgery? *Sensors*, *21*(16), 5526. https://doi.org/10.3390/s21165526

Hashimoto, D. A., Rosman, G., Rus, D., & Meireles, O. R. (2018). Artificial Intelligence in Surgery: Promises and Perils. *Annals of Surgery*, *268*(1), 70–76. https://doi.org/10.1097/SLA.0000000000002693

Herron, D. M., Marohn, M., & SAGES-MIRA Robotic Surgery Consensus Group. (2008). A consensus document on robotic surgery. *Surgical Endoscopy*, *22*(2), 313–325; discussion 311-312. https://doi.org/10.1007/s00464-007-9727-5

Holden, R. J., & Karsh, B.-T. (2010). The Technology Acceptance Model: Its past and its future in health care. *Journal of Biomedical Informatics*, *43*(1), 159–172. https://doi.org/10.1016/j.jbi.2009.07.002

Iftikhar, M., Saqib, M., Zareen, M., & Mumtaz, H. (2024). Artificial intelligence: Revolutionizing robotic surgery: review. *Annals of Medicine & Surgery*, *86*(9), 5401–5409. https://doi.org/10.1097/MS9.0000000000002426

International Organization for Standardization. (2021). *Robotics — Vocabulary (ISO 8373:2021)*. https://www.iso.org/standard/75539.html

Jauniaux, B., Anand, A., Abbas, R., & Harji, D. P. (2025). From expectations to experiences: A systematic review of patient and public perspectives on robotic surgery. *Journal of Robotic Surgery*, *19*(1), 484. https://doi.org/10.1007/s11701-025-02649-y

Jian, J.-Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an Empirically Determined Scale of Trust in Automated Systems. *International Journal of Cognitive Ergonomics*, *4*(1), 53–71. https://doi.org/10.1207/S15327566IJCE0401_04

Keles, H. D., & Eke, E. (2025). Adoption and implementation of robotic surgery in Türkiye: A multi-level qualitative analysis of individual, institutional, and systemic dynamics. *Journal of Robotic Surgery*, *19*(1), 688. https://doi.org/10.1007/s11701-025-02864-7

Khan, A., & Anwar, Y. (2020). *Robots in Healthcare: A Survey* (pp. 280–292). https://doi.org/10.1007/978-3-030-17798-0_24

Khanna, R., Raison, N., Granados Martinez, A., Ourselin, S., Montorsi, F., Briganti, A., & Dasgupta, P. (2025). At the cutting edge: The potential of autonomous surgery and challenges faced. *BMJ Surgery, Interventions, & Health Technologies*, *7*(1), e000338. https://doi.org/10.1136/bmjsit-2024-000338

Klodmann, J., Schlenk, C., Hellings-Kuß, A., Bahls, T., Unterhinninghofen, R., Albu-Schäffer, A., & Hirzinger, G. (2021). An Introduction to Robotically Assisted Surgical Systems: Current Developments and Focus Areas of Research. *Current Robotics Reports*, *2*(3), 321–332. https://doi.org/10.1007/s43154-021-00064-3

Knudsen, J. E., Ghaffar, U., Ma, R., & Hung, A. J. (2024). Clinical applications of artificial intelligence in robotic surgery. *Journal of Robotic Surgery*, *18*(1), 102. https://doi.org/10.1007/s11701-024-01867-0

Kok Wah, J. N. (2025). AI-driven robotic surgery in oncology: Advancing precision, personalization, and patient outcomes. *Journal of Robotic Surgery*, *19*(1), 382. https://doi.org/10.1007/s11701-025-02555-3

Kvale, S., & Brinkmann, S. (2009). *InterViews: Learning the Craft of Qualitative Research Interviewing*. SAGE.

Kwon, T. H., & Zmud, R. W. (1987). Unifying the fragmented models of information systems implementation. In *Critical issues in information systems research* (pp. 227–251). https://dl.acm.org/doi/abs/10.5555/54905.54915

Landi, S., Maistri, G., Orsini, L. P., Leardini, C., Malandra, S., & Antonelli, A. (2025). Supporting managerial decisions: A comparison of new robotic platforms through time-driven activity-based costing within a value-based healthcare framework. *BMC Health Services Research*, *25*(1), 470. https://doi.org/10.1186/s12913-025-12598-9

Lanfranco, A. R., Castellanos, A. E., Desai, J. P., & Meyers, W. C. (2004). Robotic Surgery: A Current Perspective. *Annals of Surgery*, *239*(1), 14–21. https://doi.org/10.1097/01.sla.0000103020.19595.7d

Lee, A., Baker, T. S., Bederson, J. B., & Rapoport, B. I. (2024). Levels of autonomy in FDA-cleared surgical robots: A systematic review. *Npj Digital Medicine*, *7*(1), 103. https://doi.org/10.1038/s41746-024-01102-y

Lee, A. T., Ramasamy, R. K., & Subbarao, A. (2025). Understanding Psychosocial Barriers to Healthcare Technology Adoption: A Review of TAM Technology Acceptance Model and Unified Theory of Acceptance and Use of Technology and UTAUT Frameworks. *Healthcare*, *13*(3), 250. https://doi.org/10.3390/healthcare13030250

Lee, J. D., & See, K. A. (2004). Trust in Automation: Designing for Appropriate Reliance. *Human Factors*, *46*(1), 50–80. https://doi.org/10.1518/hfes.46.1.50_30392

Lin, Y., Lin, P., Wang, J., Xu, M., Li, C., Rong, M., Xia, W., & Zeng, Y. (2025). Patients' Awareness, Trust, and Acceptance of Robot-Assisted Dental Implant Surgery: A Cross-Sectional Survey. *Clinical Implant Dentistry and Related Research*, *27*(6), e70109. https://doi.org/10.1111/cid.70109

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic Inquiry. *SAGE*.

Liu, Y., Wu, X., Sang, Y., Zhao, C., Wang, Y., Shi, B., & Fan, Y. (2024). Evolution of Surgical Robot Systems Enhanced by Artificial Intelligence: A Review. *Advanced Intelligent Systems*, *6*(5), 2300268. https://doi.org/10.1002/aisy.202300268

Malhotra, N., Kim, S., & Agarwal, J. (2004). Internet Users' Information Privacy Concerns (IUIPC): The Construct, the Scale, and a Causal Model. *Information Systems Research*, *15*, 336–355. https://doi.org/10.1287/isre.1040.0032

Marcus, H. J., Ramirez, P. T., Khan, D. Z., Layard Horsfall, H., Hanrahan, J. G., Williams, S. C., Beard, D. J., Bhat, R., Catchpole, K., Cook, A., Hutchison, K., Martin, J., Melvin, T., Stoyanov, D., Rovers, M., Raison, N., Dasgupta, P., Noonan, D., Stocken, D., … McCulloch, P. (2024). The IDEAL framework for surgical robotics: Development, comparative evaluation and long-term monitoring. *Nature Medicine*, *30*(1), 61–75. https://doi.org/10.1038/s41591-023-02732-7

Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An Integrative Model of Organizational Trust. *The Academy of Management Review*, *20*(3), 709–734. https://doi.org/10.2307/258792

Maynou, L., McGuire, A., & Serra-Sastre, V. (2024). Efficiency and productivity gains of robotic surgery: The case of the English National Health Service. *Health Economics*, *33*(8), 1831–1856. https://doi.org/10.1002/hec.4838

Mayring, P. (2022). *Qualitative Inhaltsanalyse: Grundlagen und Techniken* (13., überarbeitete Auflage). Beltz.

Moore, G. A. (1991). *Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers*. HarperBusiness.

Olawade, D. B., Marinze, S., Weerasinghe, K., Egbon, E., Onuoha, J. U., & Teke, J. (2025). Robotic surgery in healthcare: Current challenges, technological advances, and global implementation prospects. *Journal of Robotic Surgery*, *19*(1), 577. https://doi.org/10.1007/s11701-025-02702-w

O'Sullivan, S., Nevejans, N., Allen, C., Blyth, A., Leonard, S., Pagallo, U., Holzinger, K., Holzinger, A., Sajid, M. I., & Ashrafian, H. (2019). Legal, regulatory, and ethical frameworks for development of standards in artificial intelligence (AI) and autonomous robotic surgery. *The International Journal of Medical Robotics and Computer Assisted Surgery*, *15*(1), e1968. https://doi.org/10.1002/rcs.1968

Pal, H. (2024). Advancements and limitations in integrating robotics into medicine: A comprehensive review. *Multidisciplinary Reviews*, *7*(11), 2024248. https://doi.org/10.31893/multirev.2024248

Panesar, S., Cagle, Y., Chander, D., Morey, J., Fernandez-Miranda, J., & Kliot, M. (2019). Artificial Intelligence and the Future of Surgical Robotics. *Annals of Surgery*, *270*(2), 223–226. https://doi.org/10.1097/SLA.0000000000003262

Picozzi, P., Nocco, U., Labate, C., Gambini, I., Puleo, G., Silvi, F., Pezzillo, A., Mantione, R., & Cimolin, V. (2024). Advances in Robotic Surgery: A Review of New Surgical Platforms. *Electronics*, *13*(23), 4675. https://doi.org/10.3390/electronics13234675

Randell, R., Honey, S., Hindmarsh, J., Alvarado, N., Greenhalgh, J., Pearman, A., Long, A., Cope, A., Gill, A., Gardner, P., Kotze, A., Wilkinson, D., Jayne, D., Croft, J., & Dowding, D. (2017). A realist process evaluation of robot-assisted surgery: Integration into routine practice and impacts on communication, collaboration and decision-making. *Health Services and Delivery Research*, *5*(20), 1–140. https://doi.org/10.3310/hsdr05200

Reddy, K., Gharde, P., Tayade, H., Patil, M., Reddy, L. S., & Surya, D. (2023). Advancements in Robotic Surgery: A Comprehensive Overview of Current Utilizations and Upcoming Frontiers. *Cureus*. https://doi.org/10.7759/cureus.50415

Rogers, E. M. (1983). *Diffusion of innovations* (3rd ed). Free Press ; Collier Macmillan.

Rogers, E. M. (2003). *Diffusion of Innovations, 5th Edition*. Simon and Schuster.

Rowley, J. (2012). Conducting research interviews. *Management Research Review*, *35*(3/4), 260–271.

Saeidi, H., Opfermann, J. D., Kam, M., Wei, S., Leonard, S., Hsieh, M. H., Kang, J. U., & Krieger, A. (2022). Autonomous robotic laparoscopic surgery for intestinal anastomosis. *Science Robotics*, *7*(62), eabj2908. https://doi.org/10.1126/scirobotics.abj2908

Saqib, U., Ilyas, S., & Abdullah, M. (2025). Implementation of Artificial Intelligence (AI) into Robotic Surgical Systems. *ACADEMIA International Journal for Social Sciences*, *4*(3), 2611–2624. https://doi.org/10.63056/ACAD.004.03.0552

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. john wiley & sons. https://books.google.com/books?hl=de&lr=&id=Ko6bCgAAQBAJ&oi=fnd&pg=PA1

9&dq=Sekaran,+U.,+%26+Bougie,+R.+(2016).+Research+methods+for+business:+A+skill-building+approach+(7+ed.):+Wiley.&ots=2D3U-2J_oM&sig=H_hDG4UpWmM9YMquypcnwSy_atM

Taghipour, N., Mostafavinia, A., Hosseini, S., Javaherinasab, M., Mehran, H., Alighadr, A., Javankiani, S., & Dehbozorgi, S. (2025). Surgeon Attitudes Toward AI-Enhanced Robotic Surgery: A Survey on Autonomy, Liability, and Skill Erosion. *InfoScience Trends*, *2*(6), 29–41. https://doi.org/10.61186/ist.202502.06.03

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, *28*(13), 1319–1350. https://doi.org/10.1002/smj.640

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509–533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7%3C509::AID-SMJ882%3E3.0.CO;2-Z

Tornatzky, L. G., & Fleischer, M. (1990). *The processes of technological innovation*.

Turner, D. (2014). Qualitative Interview Design: A Practical Guide for Novice Investigators. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2010.1178

Varghese, C., Harrison, E. M., O'Grady, G., & Topol, E. J. (2024). Artificial intelligence in surgery. *Nature Medicine*, *30*(5), 1257–1268. https://doi.org/10.1038/s41591-024-02970-3

Vasey, B., Lippert, K. A. N., Khan, D. Z., Ibrahim, M., Koh, C. H., Layard Horsfall, H., Lee, K. S., Williams, S., Marcus, H. J., & McCulloch, P. (2023). Intraoperative Applications of Artificial Intelligence in Robotic Surgery: A Scoping Review of Current Development Stages and Levels of Autonomy. *Annals of Surgery*, *278*(6), 896. https://doi.org/10.1097/SLA.0000000000005700

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward A Unified View. *MIS Quarterly*, *27*(3), 425–478. https://doi.org/10.2307/30036540

Wah, J. N. K. (2025a). Revolutionizing surgery: AI and robotics for precision, risk reduction, and innovation. *Journal of Robotic Surgery*, *19*(1), 47. https://doi.org/10.1007/s11701-024-02205-0

Wah, J. N. K. (2025b). The rise of robotics and AI-assisted surgery in modern healthcare. *Journal of Robotic Surgery*, *19*(1), 311. https://doi.org/10.1007/s11701-025-02485-0

Yang, G.-Z., Cambias, J., Cleary, K., Daimler, E., Drake, J., Dupont, P. E., Hata, N., Kazanzides, P., Martel, S., Patel, R. V., Santos, V. J., & Taylor, R. H. (2017). Medical robotics—Regulatory, ethical, and legal considerations for increasing levels of autonomy. *Science Robotics*, *2*(4), eaam8638. https://doi.org/10.1126/scirobotics.aam8638

Yeater, K. M., Duke, S. E., & Riedell, W. E. (2015). Multivariate Analysis: Greater Insights into Complex Systems. *Agronomy Journal*, *107*(2), 799–810. https://doi.org/10.2134/agronj14.0017

Zhang, C., Hallbeck, M. S., Salehinejad, H., & Thiels, C. (2024). The integration of artificial intelligence in robotic surgery: A narrative review. *Surgery*, *176*(3), 552–557. https://doi.org/10.1016/j.surg.2024.02.005

Appendix

Appendix A: Semi-structured Interview Guides

A.1 Semi-structured Interview Guide: MedTech

Interview guide: MedTech	
Introduction	o Could you briefly describe your role and what exactly you are doing.
Market Understanding & Routinization classification	o From your deployment experience across hospitals, which stage on the adoption curve best describes where most hospital clients currently are? (DOI S-curve) o What most often prevents hospitals from moving to the next stage toward routine use? o What is the difference between adoption and routinization from your point of view? o From your observation, which actors/ reference groups influence whether a hospital moves toward routine use? o What clinical, technological, environmental or regulatory trends are currently driving demand for higher levels of surgical robotic autonomy?
Implementation Requirements & Routinized Use	o What are the benefits of the semi-autonomous surgical robots also in the collaboration? o Once a hospital decides to implement such a system, what capabilities and resources are needed? o What must be changed or reconfigured inside the hospital after deployment for the system to enable routinized use? o What do hospitals most often underestimate what is needed to absorb and operationalize the technology? o What integration challenges arise most often when hospitals move from initial deployment toward routine use?
Regulatory Environment & Collaboration	o How do current regulatory requirements affect the introduction and routine use of AI-enabled semi-autonomous surgical systems? o To what extent do reimbursement structures and financial incentives for hospitals act as barriers or drivers for routine use of such systems in practice? o What information / feedback from real-world clinical deployments is most important for improving the system and supporting routine use?
Trust & Post-Deployment	o What role does surgeons and patients trust play in the routinization? o What most often damages surgeons' trust in the system after deployment? o How do you manage changes to the AI model after deployment without undermining trust surgeons have already calibrated toward the previous system behaviour? o What helps to maintain surgeons and hospitals trust after implementation? o How important is social influence and the commitment from the management to reac routinization? o What role does the professional identiy play – skill erosion or deskilling fears?
Outlook	o In your view, what happens to hospitals that do not build these capabilities while comparable hospitals do? o Is there anything important that has not yet come up in our conversation - something you would consider critical for understanding what it takes to make this technology part of everyday clinical practice?

A.2 Semi-structured Interview Guide: Physician

Interview guide: Physician	
Introduction	o Could you briefly describe your role, surgical specialty and clinical setting?
Experience & Definition of Routine Use	o What experience do you have with surgical robotic systems (e.g., da Vinci) - or are such systems currently used at your hospital? o How has your experience with the system evolved the more frequently you have used it? o How would you define routine use of semi-autonomous surgical robotic systems?
Integration & Routinization	o Where do you see the greatest benefit of semi-autonomous robots in your daily work o What organizational and technical prerequisites are needed for reliable day-to-day routine operation? o Does integrating such systems require changes to workflow and coordination within the OR? To what extent does this represent a barrier to routine use? Is it also necessary to adapt role profiles within the OR team o What would you and your team need to use such systems safely and confidently in everyday surgical practice? o What would most likely prevent routine use of such systems in your daily clinical work?
Trust & Professional Identity	o What would you need to use such a system safely and confidently in routine practice over the long term? o What would cause you or your colleagues to go back to less autonomous approaches after an initially positive phase? o Do you believe that regular use of semi-autonomous surgical robots would change your own surgical expertise, decision-making, and skill development over time? o To what extent does this affect your willingness to use such systems? o What role do patients and their trust play in the routinization of such systems?
Social Influence & Diffusion	o To what extent does routinization depend on support from hospital management and senior clinical leadership? o How does adoption spread among surgeons in your department or network - are there clearly identifiable early adopters, and how does their experience influence colleagues?
Institutional Condition & Governance	o Which people or departments outside your immediate OR team need to be involved in the implementation process? o Which external conditions have the strongest influence on whether such systems reach routine use? (e.g., reimbursement structures, data protection, cybersecurity, governance, regulatory requirements) o How does the liability and accountability question influence the routine use of surgical robotics? o How could internal or external guidelines support routine use - and which ones would be necessary?
Outlook	o Do you see ownership of such a system as a competitive advantage for a hospital — or not? o Is there anything that we did not cover which you feel is important or you want to contribute?

A.3 Semi-structured Interview Guide: Researcher

Interview guide: Researcher	
Introduction	o Could you briefly describe what you are doing and what your research or work focus is in the context of digital health.
Defining Routinization & Adoption Dynamics	o From your perspective, when does the use of an AI-enabled semi-autonomous surgical system count as routinized use rather than pilot use, selective use, or showcase use? o When you look at technologies that move from first implementation into stable day-to-day clinical practice, what seems to distinguish them from those that do not? o From your perspective, how does the perceived complexity of working with semi-autonomous surgical systems affect whether surgeons and hospitals move from initial use to routine practice?
Organizational Capabilities & Integration	o What organizational prerequisites do you consider essential for a semi-autonomous surgical robotic system implementation and sustained routine use? o To what extent do technical conditions act as enablers or barriers to routine use in practice? o What role do training, competence development, and learning curves play in enabling routine use? o How important is social influence and leadership commitment for the routinization of digital technologies in healthcare? o After a system has been introduced, what typically still needs to be adapted or managed over time for routine use to be sustained?
Trust, Human Oversight & Workflow	o What role does trust play in whether semi-autonomous surgical systems become part of routine clinical practice? o What is necessary for surgeons and hospitals to trust not only the system itself but also the human-robot collaboration during routine care? o What kinds of workflow or team-related challenges do you see as especially relevant for routine use? o Under which conditions do transparency, explainability, and predictability of system behavior become especially critical for routine use?
Governance, Regulation & Institutionalization	o What governance arrangements does the evidence suggest are most critical for enabling routinized use - rather than just initial adoption - of semi autonomous surgical systems? o Where do you see the most consequential misalignments between current regulatory frameworks and the practical realities of routine clinical deployment? o How strongly do environmental conditions - such as reimbursement structures, competitive pressure between hospitals, or market incentives - shape whether these systems reach routine use? o What should policymakers and governments prioritize to support the routinized use of AI-enabled semi-autonomous surgical robotic systems while maintaining ethical, privacy, and safety standards?
Outlook	o What are the consequences for hospitals that do not develop these capabilities while comparable institutions do? o Is there anything important that has not yet come up that you consider critical for understanding what drives or hinders routinized use in hospitals?

Appendix B: Interview Summaries

B.1 Interview Summary EI1

Block A—Market Understanding & Routinization: The current adoption rate is at an early-adopter stage because financing is a major barrier to broader diffusion. The funding options are rather limited. University hospitals receive grants and therefore drive social diffusion through publications and conferences, motivating other doctors to consider new technology. But routinization often fails on the economic level: technology that fails to generate financial return is eliminated.

Block B—Implementation Requirements & Routinized Use: EI1 mentions that staff resistance is often underestimated, and you need the right staff to support semi-autonomous surgical robots. Successful implementation needs the right OR sizes, a change in OP scheduling, sterilization, logistics, and procurement. Additionally, maintenance staff and continuous training is essential. Data protection and cybersecurity are also bottlenecks since the surgical robots collect and process a large amount of data. What drives routinization is the benefits for the patient and the standardization of care. A robot works the same after 25h, but a doctor does not.

Block C—Regulatory Environment & Collaboration: The MDR is a huge implementation barrier, audibility is difficult, and risk analysis is complex for non-deterministic AI systems. Liability is still unclear in cases of errors, showing the same problems as with autonomous vehicles. Feedback through incident reporting back to the manufacturer is often limited because of workload pressure, which limits iterative system improvement, which is essential.

Block D—Trust & Post-Deployment: Routinization is reached when surgeons delegate tasks to the system consistently without hesitation. Communication, ongoing training and transparency are key. But a single serious failure can permanently damage confidence and trust in the system. Software updates need transparent communication and phantom-based training before clinical deployment. For patients, trust depends on communication that keeps the surgeon's supervisory role visible and central.

Block E—Outlook: EI1 mentioned that smaller hospitals have disadvantages since they do not have the financial capacity and will never reach the case volumes, making the investment difficult. A larger hospital will gain efficiency and attract technology affine patients. EI1 stated that clinical adoption requires a credible narrative; AI-assisted systems relieve and support surgeons. They do not replace them.

B.2 Interview Summary EI2

Block A—Market Understanding & Routinization: EI2 stated that most hospital are at the early adopter stage because of infrastructure barriers, especially power supply limitations. Staff and hospital organisation resistance exists to changing established workflows and using new technology. The cost is also a barrier, since the technologies are very expensive as an investment but also in the ongoing maintenance. On top the trust of surgeons and patients' needs to be there before routinization can be reached.

Block B—Implementation Requirements & Routinized Use: EI2 stated that the benefits of semi-autonomous systems, such as precision, consistency, and no tiredness or anxiety, are what drive routinization. There is a need for technical staff support, ongoing hardware and software checking, and regular maintenance.

Block C—Regulatory Environment & Collaboration: Regulations are a hurdle since data governance is a structural challenge. Surgical footage from patients touches confidentiality, making it difficult to use for AI training. Technical stakeholders push the adoption while clinicians pull back. When considering cost without broader standardization, the systems will remain out of reach for most hospitals regardless of clinical interest.

Block D—Trust & Post-Deployment: Trust in the system needs to be gained. Surgeons need ongoing training and a clear explanation of what the robot can and cannot do. EI2 stated that showing surgeons that the technology is there to help and augment them, not to take their job

away, is essential. On top, patients often have a misconception of surgical robots that needs to be eliminated in order to gain their trust and acceptance.
Block E—Outlook: Hospitals that implement and are able to use semi-autonomous surgical robots will increase operational efficiency and gain patients because of a certain level of compatibility and an actual up-to-date lifestyle.

B.3 Interview Summary EI3

Block A—Market Understanding & Routinization: EI3 placed current adoption between the innovator and early adopter stages since human-powered surgeries are still cheaper. The clinical staff shortage motivated robotic surgeries, but the cost is a barrier since only well-capitalized hospitals will be able to implement and routinize the use. Research and publication-driven institutes are the early adopters, who will influence other senior surgeons to use it. Routinization is reached if the robot is treated as a conventional instrument and an established tool for training. Barriers are MDR regulations since it is difficult to present safety, and no large-scale provider is at a price point that enables standardized uptake. The benefits of semi-autonomous robots are what drive adoption since they open new ways of operating that were not possible before through precision and consistency.
Block B—Implementation Requirements & Routinized Use: EI3 stated that technical maintenance required educated staff and the reliance on the manufacturer. Workflow integration is difficult, and there needs to be a dedicated staff member who is responsible for the integration of the robot into the workflow. Consumables, procurement, and scheduling all need continuous reconfiguration around the system. EI3 recommends an on-premises, on-edge architecture of the robot to manage cybersecurity risk and avoid electromagnetic interference with other OR devices.
Block C—Regulatory Environment & Collaboration: EI3 mentioned that regulations such as MDR are very difficult, preventing in vivo use. Also, reimbursement structures and funding are barriers, since human workflow is still cheaper, as workflow disruptions occur.
Block D—Trust & Post-Deployment: EI3 stated that the surgeon's trust is essential, and it often breaks if the system behaves differently from the surgeon's habits. Control sensitivity and translation ratios that diverge from intuitive movements create friction that erodes confidence. There needs to always be a pull by the surgeons who want to use the technology, since EI3 thinks that a push never works. Ambassadors who already use the technology or find it interesting are the way to spread technology. Ongoing training and explanation need to be

established in order to reach routinization. A problem is going to be updated that may trigger new regulatory approval requirements.
Block E—Outlook: EI3 does not expect a competitive advantage soon, since SASR remain viable only for highly specialized centres. Routinization will also be different based on the country we are looking at. China is expected to move faster and on a greater scale.

B.4 Interview Summary EI4

Block A—Experience & Definition of Routine Use: EI4 had assistive roles during robotic surgeries, with a lot of training on simulation-based repetition. Semi-autonomous robotics are beneficial in difficult operations such as intra-abdominal procedures with high adhesions, where conventional manual access is very difficult or not possible. Routinization is for EI4 if the surgeons use it consistently and achieve demonstrably better outcomes.
Block B—Integration & Routinization: Advantages of using semi-autonomous robots during surgery are reduced physical fatigue and better outcomes for the patients. But the preparation time before the operation takes longer, and the financial cost is high. The OR size needs to be available, specialized sterilization capacity, and a trained staff team of surgeons, nursing staff, and maintenance personnel is necessary. Essential is more standardized training that is ongoing to build competence across all OR staff.
Block C—Trust & Professional Identity: The trust of surgeons is essential, and therefore, training and explanations are needed to increase their confidence with the system. EI4 raised the concern of cognitive passivity, meaning excessive reliance on robotic systems risks deskilling and overreliance over time.
Block D—Social Influence & Diffusion: Trainees learn through the operating style of their senior supervisor and mostly adopt it. EI4 mentioned that diffusion depends on social influence, seeing others already using it.
Block E—Institutional Conditions & Governance: Internal governance is essential, especially because of liability and responsibility. Ei4 raises concerns about who is responsible if an error occurs.
Block F—Outlook: EI4 stated that in the future, hospitals with such a technology will get a competitive advantage in the future.

B.5 Interview Summary EI5

Block A—Experience & Definition of Routine Use: For EI5, routinization is reached if team coordination is nearly automatic and the workflow runs almost without communication. EI5 stated that the pre-operative preparation of a surgical robotic system required more time due to the complex setup and multiple connective steps. But during the operation, it is more comfortable for an OR nurse since instrument changes are less frequent with the use of the robotic system.

Block B—Integration & Routinization: EI5 stated that clinical advantages range from enhanced 3D visualization, superior depth of access, fewer instrument exchanges, and utility for intraoperative teaching through screen annotation. But limitations in hospital OR room sizes and sterilization requirements are infrastructure constraints that hospitals underestimate. There needs to be someone internally who takes responsibility if something goes wrong, and technical support is essential; the best would be vendor presence. Training is the most needed resource, and it has to be ongoing and not only in the implementation phase. The financing also needs to be in place since it is not only the initial technology price, but it also costs to keep the machine running. Change resistance is cultural rather than technical, and the shift in OR nurse role profiles as instrumentation tasks diminish needs to be managed deliberately. With the introduction of semi-autonomous robotic systems, the workflow and roles also change, as well as scheduling plans.

Block C—Trust & Professional Identity: EI5 mentioned insufficient training as the primary driver of individual resistance. A malfunction that left a patient under anesthesia for over an hour, represents the kind of event that, if repeated, would lead to diminished surgeons' trust or even abandoning the technology. The fear of deskilling and skill erosion is notable, and EI5 also stated that she knows colleagues who feel the fear. EI5 mentioned the patient's misconception of what the robot looks like or who is operating it. Therefore, new communication ways necessary to declare the misconception.

Block D—Social Influence & Diffusion: EI5 stated that diffusion happens through peer trust. Observing positive outcomes and word of mouth is the most effective way of diffusion. Also, hospitals measure themselves against each other, which increases routinized use since new technology adds prestige to a hospital.

Block E—Institutional Conditions & Governance: Internal governance, such as fixed, predictable schedules, enables structured preparations, and everyone can plan accordingly. On top, responsible persons, clear contact protocols, and verifiable training records for everyone who is working with the system need to be established.

Block F—Outlook: EI5 said that already the use of surgical robotics, such as DaVinci, is a marker of prestige, and a semi-autonomous system will extend that further. A problem is that patients' education has not received much attention, but this is essential since misconceptions about robotic surgery are widespread, and informed consent cannot happen until patients are educated.

B.6 Interview Summary EI6

Block A—Experience & Definition of Routine Use: EI6 stated that adoption is unique since it is constrained by evidence-based medicine. Routinization depends on cost-per-patient justification, infrastructure readiness, training capacity, and sufficient institutional volume. This is not yet given in most hospitals. The benefits for the patient drive routine use, such as lower blood loss or fewer complications.

Block B—Integration & Routinization: EI6 considered the standardization of procedures, cognitive load reduction, and support for less experienced surgeons as the most valuable benefits. The paradox is that initial deployment will reduce throughput before it improves it. EI6 stated the theatre shortage, not large enough operating rooms, infrastructure that is not designed for robotic systems, limited trained operator availability, and lifecycle funding requirements as a barrier towards routinization. On top of that, cultural resistance among hospital staff is huge. Cultural acceptance is necessary and can be reached through transparent communication.

Block C—Trust & Professional Identity: EI6 acknowledged trust as an essential prerequisite. Operating room staff need to be trained through ongoing simulations, workshops, and training. It might be advantageous for surgeons to fulfil a certain time requirement for training with the technology. Patients' trust is also essential, and current consent forms do not adequately address robot-specific complication scenarios. Liability and responsibility are also unresolved, which needs to be addressed, since it raises concerns from surgeons. Ei6 stated that deskilling is a recurring fear, but this might depend on the age of the surgeon since there is also the possibility to learn new competences.

Block D—Social Influence & Diffusion: EI6 said that diffusion follows the classic surgical training sequence: see, do, teach. Being able to see positive outcomes by other respected colleagues is more effective than evidence data alone.

Block E—Institutional Conditions & Governance: EI6 stated that everyone from clinical lead to theater manager needs to be involved because you need the support of the management to be able to purchase such expensive technology, and because semi-autonomous robotic systems really change the whole way of working. Cybersecurity is a risk that needs to be limited. Recently, NHS data breaches have eroded trust in digital health systems in the UK. Having clear internal guidelines is essential for standardized care.
Block F—Outlook: A semi-autonomous robotic system can be an advantage in attracting surgeons. Ei6 stated that there is a trend that certain surgeons tend to go to hospitals that offer modern technologies.

B.7 Interview Summary EI7

Block A—Market Understanding & Routinization: EI7 categorized hospitals as the innovation and early adopter stage with the bottleneck being rarely the technology itself. The organizational system, absent workflow integration, and unclear internal ownership are the barriers for routinization. Through peer ambassadors and opinion leaders' technology diffuses internally and externally.
Block B—Implementation Requirements & Routinized Use: EI7 stated that getting the infrastructure right is very important. But often human reliance is underestimated. The learning curve for staff members is deep, but initial frustration can stall further use. EI7 acknowledged that the real work is not implementation but the work after, with ongoing training, finding internal people who believe in it, and not letting momentum die when the initial enthusiasm fades. The benefits of semi-autonomous surgical robots are the driver for the routine use. But the interoperability and integration into workflows is very difficult.
Block C—Regulatory Environment & Collaboration: EI7 stated that EU MDR and AI Act make things slower and more complicated, but they also make patients and clinicians more willing to trust the technology. In the view of EI7, the compensation systems are essential, as well as reimbursement and funding. There also needs to be coordination between management, IT, procurement, and clinical staff early on.
Block D—Trust & Post-Deployment: EI7 stated that healthcare is a business of trust, and people do not trust what they can not understand. Different recommendations from what the surgeons would have done or decisions that are not explainable, reduce trust and reliance. Trust needs to be maintained actively, updated needs to be thought out and explained, communication needs to be clear, and training needs to be current. EI7 also said that watching a colleague use the

system in the OR, seeing it work in real time, does more than any training session. The commitment of the management is essential as is that of surgeons, because one additional click can decrease motivation to use the technology.
Block E—Outlook: EI7 stated that hospitals that fail to use SASRS will naturally fall behind since technology becomes an increasingly key differentiator for hospitals.

B.8 Interview Summary EI8

Block A—Market Understanding & Routinization: EI8 declared hospitals are still at the early adopter stage because of structural barriers. Routinization is defined by EI8 at the point where the technology is no longer needed to be mentioned and is part of the workflow. A restraining point is also the DRG system, since extra AI functions rarely get reimbursed.
Block B—Implementation Requirements & Routinized Use: To reach routinization, EI8 stated training as the most needed resource. Regular emergency drills throughout routine use are essential. Clear explanation, education, and communication are essential, as well as a monitoring system. Stakeholder inclusion is often overlooked, so it is not enough to align surgeons; you need to train the whole OR team. Physical constraints such as the OR size and equipment weight are barriers.
Block C—Regulatory Environment & Collaboration: EI8 noted that the MDR is a huge barrier, and the liability asymmetry is an additional barrier. Data security is also a real problem in hospital settings. This might be resolved by anonymization of data. Reimbursement and financial resources offer an additional barrier. Not only is the high initial price but the ongoing maintenance cost is also a barrier.
Block D—Trust & Post-Deployment: EI8 stated that patients often do not understand what semi-autonomous robotic surgery involves and that confusion doesn't fix itself. So clear and transparent education is needed. Often, among physicians, resistance follows seniority. When updates are necessary, clear instructions and explanations are needed since changed interfaces or habits damage trust. Skill erosion is a fear among surgeons, but structured training systems and simulations can reduce the anxiety.
Block E—Outlook: EI8 stated that the pace of routinization depends mostly on how regulations around explainable AI develop. Hospitals won't directly fall behind since the adoption is still far in the future, but technology will be a differentiator for hospitals.

B.9 Interview Summary EI9

Block A—Defining Routinization & Adoption Dynamics: EI9 stated that routinization has been reached when nobody asks how to operate a system anymore. The perceived complexity of robotic surgery comes less from the technology than from the existing training gap, and with the additional preparation times, it takes initially longer than a conventional procedure.

Block B—Organizational Capabilities & Integration: EI9 stated that the implementation of SASRS need medical engineering, IT data protection, structural capacity, such as the weight and size of the robot fitting into existing OR rooms, and the willingness of early adopters. The best motivation after EI9 is the motivation from within the surgeons, often driven by prestige thinking, while nursing staff needs top-down direction. EI9 stated that routinization depends on high-volume, tight-scheduled case series so that gaps do not cause skill loss, and because sporadic use does not build competencies. To cluster cases from simple to complex is a good strategy. On top of that, consumables are an ongoing cost because single-use components are expensive. Peer teaching designed by responsible staff is the best training model mentioned by EI9.

Block C—Trust, Human Oversight & Workflow: Trust of surgeons and patients is essential, but patients' trust in the robotic system is based on evidence-based outcomes. EI9 mentioned the daVinci case, where adoption was also driven by patients; this could also be the case with semi-autonomous robotic systems. A big structural problem in German hospitals is the separation between surgical and nursing management hierarchies, which blocks coordinated adoption.

Block D—Governance, Regulation & Institutionalization: EI9 stated that DGRP creates a systematic operational burden across the hospital domain. In Germany, financial incentives drive institutional decisions. Therefore, without clear revenue benefits, investments are not made. Financial reimbursement is limited, and funding models are a hurdle to adoption and to routinization. Adoption can be pushed from within through mandatory robotic case quotas or procedure privileges tied to robotic surgery volumes.

Block E—Outlook: EI9 said that in the short term, non-adoption will not hurt most hospitals, but robotic surgery is a genuine differentiator. The hospital he is researching and working at is advanced in robotics to have a unique selling point. EI9 additionally state that deskilling is not only theoretically documented but also happening in the hospital where he is working. Cases there exist that robotic specialists are unable to perform open surgery when systems fail. Honest public communication about the technology and ongoing simulation-based training infrastructure are the way to reach routinization.

B.10 Interview Summary EI10

Block A—Market Understanding & Routinization: EI10 stated that AI-enabled robotic surgery sits below 16% penetration in Western countries and even lower globally. Therefore, it is still at the early adopter phase. EI10 defined routinization as a consistent, indication-based deployment where it demonstrably shows outcome improvements. The main barrier to routine use is financial, because there are high acquisition costs combined with almost no reimbursement, pushing towards the patients. This, in return also gaps eligible case volume. Additionally, hospitals run business case logic on these investments, weighing patient volume, staff savings, and throughput, which do not look advantageous towards adoption and routinization.

Block B—Implementation Requirements & Routinized Use: EI10 stated that physical requirements are substantial, such as OR space, supplies, qualified staff, and a dedicated on-site technician. But the harder problem is interoperability since connecting a new system to a hospital ecosystem with mixed vendors, and sometimes paper-based workflows, is a huge barrier phased. Change resistance is especially given in the medical environment, but EI10 said that when users understand the value clearly, this can be fixed. Post-acquisition training that is ongoing can lead to routine use.

Block C—Regulatory Environment & Collaboration: Regulatory approval pathways are long, inconsistently defined across regions in Germany, and are not supported by an expert assessment capacity. Moreover, reimbursement is a barrier because, without coverage, routine use stays limited to patients who can pay privately.

Block D—Trust & Post-Deployment: For EI10, trust is sequential: surgeons first, patients through them. Trust can be permanently damaged by one adverse outcome linked to the robot recommendation and, therefore routine use. Even though statistically adverse outcomes are rare, reputational damage does not scale with frequency. There is the hurdle of the so-called black box problem, but EI10 stated out of experience that surgeons care more about reliable performance than algorithm transparency. The engagement of vendors and simulation-based training is essential to keep routine use. EI10 mentioned that the status of surgeons is a big topic and technology that might take the prestige and professional identity away, which feels for them like a loss of their standing. For EI10, the resistance does not respond to technical arguments.

Block E—Outlook: EI10 stated that hospitals not able to use a semi-autonomous robotic system routinely may lose patient volume, but the pressure depends on how broadly the sector moves. And two pressure points for robotic surgery are workforce shortage and demographic aging.

B.11 Interview Summary EI11

Block A—Market Understanding & Routinization: EI11 placed adoption at the early adopter, more innovator phase, since the current barrier for semi-autonomous robotic systems is still technology immaturity. Many are still prototypes, not yet ready for clinical development at scale. The precision and real-time accurate decisions with a zero-tolerance for errors are a barrier that technology still needs to overcome. EI11 defined routinization, where semi-autonomous robotic-assisted surgery no longer needs special patient consent, and it became standard practice.

Block B—Implementation Requirements & Routinized Use: EI11 defined the benefits of semi-autonomous surgical robots, such as better precision, especially for less experienced surgeons, faster tumor detection, ergonomic relief for the surgeon, and it can be a cost advantage after the steep learning curve, so that surgeons can see more patients since routine tasks are overtaken by the robot, only needing an assistant to oversee. Difficult is to integrate the robot into the workflow and adjust it to operating room sizes. Continuous training after implementation and also system updates is necessary to drive routine use. Additionally, surgeons need to adapt their individual operative style, which is an obstacle and resistance that needs to be overcome.

Block C—Regulatory Environment & Collaboration: EI11 stated that certification and commercialization for surgical robots are a long way off and there are many regulatory hurdles. Germany's statutory insurance framework limits reimbursement flexibility. In Germany, it is almost not possible to charge for premium operations, which is the case in the US. For hospitals to do such a huge investment, the ROI must be shown through throughput, staff savings, or better patient outcomes. EI11 also said that data privacy adds tension. Patients do not want to share their data, which makes it difficult to train the system, but robust data collection is essential.

Block D—Trust & Post-Deployment: EI11 stated that patient and surgeon trust is essential to reach routine use. Surgeons lose trust if something unexpected happens or if the system behaves differently to what they are used to. Often, established surgeons exhibit underreliance on the system because of their belief that they perform better than the system, as they have done it for years. Resistance to new technology and change is a huge barrier in the medical field, as EI11 stated. Younger surgeons are often more open since it feels more like an asset rather than a threat to use a semi-autonomous surgical robot. What is essential is to integrate robotics into surgical training early on, so collaborations during operations become normal.

Block E—Outlook: EI11 stated that in the near term, no competitive advantage will be achieved since it is still a long way to go, but over time, the hospitals without robots will love the ability to offer certain procedures, and as robotic surgery becomes the standard care, patients will select hospitals with robotic systems.

B.12 Interview Summary EI12

Block A—Experience & Definition of Routine Use: EI12 defined routinization based on three measurable markers: completing a procedure within a specific time frame, movement profiles that demonstrate precision in automated instrument handling, and a stable stress level among the OR team. For EI11, it is essential to include nursing staff in the robotic training from the start since surgery is a team effort. Trainees should also work with a robot early on in residency, before other ways of working can be formed.

Block B—Integration & Routinization: EI12 stated benefits for patients and the surgeons by introducing semi-autonomous functions, such as a monitoring function alerting the surgeon to complications. On the other side, patients' trust as well as the surgeons are a major issue. Patients are quite skeptical about who is really operating and have a misconception of robotics. The legal component is also very relevant for surgeons: who is responsible and liable for mistakes? Data protection concerns around individual patient data are a huge barrier. For semi-autonomous action, the data is essential. On top. The resistance of doctors is inevitable, and the role of assistant and scrub nurses needs to be adapted if semi-autonomous robots are routinely used.

Block C—Trust & Professional Identity: EI12 argued for a structured training pathway. Moving from the dry lap to the patient. And the training needs to be continuous. For a surgeon to form trust, it is important to know where the decisions come from and not the underlying algorithms behind them. This is also relevant for patient education. The patient consent process also needs to be revised. Already in hospitals, there is a data flow transparency problem that needs to be institutionally resolved, especially when semi-autonomous robotics comes into place, since large data volumes go in and out of the system. Skill erosion is a risk mentioned by EI12 since some competencies won't be used anymore.

Block D—Social Influence & Diffusion: EI12 stated that management commitment is essential since they are deciding the investment and are the ones who communicate to the outside. Diffusion runs through trusted peer conversations that already have hands-on experience.
Block E—Institutional Conditions & Governance: EI12 mentioned that the financial situation is problematic since German DRG reimbursement was calibrated historically and does not reflect current cost realities, such as wage inflation, energy, and equipment costs. Getting technology approved is a very time-consuming and bureaucratic process that hinders the introduction of great innovations. Internally, comprehensive governance is needed, such as SOPs covering every surgical step. The integration of the entire workflow from the nursing unit to the postoperative teams needs to be aware of what is going on.
Block F—Outlook: In the view of EI12, cost reduction determines whether robotic surgery can scale into routine use. Competitive advantage can only be reached through a decrease in patient skepticism and proactive image management. EI12 is optimistic about the technology, but structural reform of healthcare financing needs to come first.

B.13 Interview Summary EI13

Block A—Defining Routinization & Adoption Dynamics: EI13 defined routinization based on the Technology Readiness Level framework. Adoption sits at TRL 8, while routinization starts at TRL 9-10, where the technology is not an exception but an invisible part of daily routine. The benefit of SASRS are democratization, meaning expert knowledge can be scaled up and made available for many hospitals. Productivity gains are reached through replacing time-intensive assistive tasks, freeing up surgeons for high-value work.
Block B—Organizational Capabilities & Integration: EI13 stated that training is necessary not only with the surgeon but with the technicians, anesthesia nurses, and the entire staff relevant to a robotic surgery. System updates require ongoing training to keep an understanding of the system and trust high. Less experienced surgeons could operate with robotic assistance under remote senior supervision, turning a deskilling risk into a distributed teaching model. Data storage is a problem, and local servers need to be in place. Interoperability with legacy hospital IT is often a failure point. On top of that, user-friendliness with the robot needs to be guaranteed.
Block C—Trust, Human Oversight & Workflow: EI13 stated that surgeons need to have predictive and reliable procedures, and their resistance to change is high. They have been doing an operation for multiple years, the same way, making it harder to gain their trust for new technologies. Therefore, it is essential that robots are easy to use and can be individualized

based on the surgeon's habits. Workflow integration is difficult, and a lot of change in surgeons' behavior and role profiles will follow. For patients: human oversight remains a safety imperative.

Block D—Governance, Regulation & Institutionalization: The EU MDR is a major barrier. EI13 cites a two-year approval process for a non-invasive software study involving twelve patients. In comparison, the FDA in the US responds faster, making it easier to develop new medical technology. EI13 mentioned internal governance should mandate verified training before system use and also during it to reach seamless routinization. Commitment from the management board is essential, since they make the investments. EI13 suggested that there is a need for a positive culture of error management where we discuss mistakes to learn from rather than covering them up.

Block E—Outlook: The domain constraint for AI development in the medical field is annotated surgical video and kinematic training data. In the far future, SASRS will be differentiators between hospitals.

B.14 Interview Summary EI14

Block A—Experience & Definition of Use: EI14 said that routinization is achieved when the non-use of robots requires documentation rather than use. This is already the case at his hospital with the daVinci system. And additionally, universal staff competence is another implication. Every OR member, assistant, or surgeon needs to be able to fulfil the role and work together with a semi-autonomous robotic system. It is therefore not a matter of individual expertise but of institutional capabilities.

Block B—Integration & Routinization: IT-Infrastructure is a huge barrier since new systems require full hospital-wide IT embedding. This pushed already overstretched IT departments to their limits as EI14 experienced. Physical OR space and multi-level training programs across all surgical levels are further logistics and resource requirements. On the technical side, the lack of scalability of narrow AI models beyond scientific settings, and extreme bureaucratic obstacles around data transfers are additional hurdles. OR role requirements are shifting, and the benefits for surgeons could be by overtaking repetitive tasks and relieving tight daily schedules.

Block C—Trust & Professional Identity: EI14 mentioned that patients have a misconception of robotic surgery, but a lot of patients already directly ask for robotic surgery due to its minimal invasiveness. For surgeons' trust, EI4 recommended simulation and continuous retraining as essential. Regulation approval is a precondition for his own confidence in the system. Change resistance within the surgeon staff is common – anything new is inherently harder than established routine. But EI14 also acknowledged an important point: not AI will replace surgeons, but surgeons who use AI will replace those who don't.

Block D—Social Influence & Diffusion: Diffusion is primarily driven by competitive pressure such as patients, marketing, and branding. Within institutions, the support and commitment of hospital management and department leaders is essential since they have an influence on other surgeons to try the new technology.

Block E—Institutional Conditions & Governance: EI14 identified the MDR and AI Act as hurdles, creating a very strict approval environment than in the US. EI14 expressed concerns about unresolved liability questions for AI-caused harm during surgery. Internally, data protection regulations are a barrier. Financially, break-even analysis allows investment decisions, but the consumable cost, even after the initial purchase prices, is high, which presents an ongoing financial burden. Reimbursement structures are unclear, therefore providing no adoption incentive. Very important are internal SOPs to anchor robotic procedures into the daily clinical work.

Block F—Outlook: In a few years, semi-autonomous surgical technologies are going to be a competitive advantage, as EI14 mentioned. Technology is always a differentiator for hospitals, just as daVinci is right now. Case volume is very important. Hospitals with only a few operations with robotic systems should not invest in a complex system. Specialization and centralization are, in EI14's view, the way to go.

B.15 Interview Summary EI15

Block A—Defining Routinization & Adoption Dynamics: EI15 stated that routinization is reached if surgeons use the technology comfortably during standard procedures. The structural shift from implementation towards routinization is from research or innovation funding to coverage through standard reimbursement structures. EI15 defined complexity and adoption readiness as specialty-dependent: surgeons already familiar with a daVinci, for example, are more likely to accept higher autonomy than those who are not.

Block B—Organizational Capabilities & Integration: IT departments need to be open 24/7 with the technical capacity to troubleshoot critical system failures within minutes. This is for Ei15, a non-negotiable prerequisite, given the life-critical nature of mid-procedure network incidents. Training must go beyond technical operation to include clinical judgment about when not to use the system, as over-enthusiasm and inappropriate application can generate adverse outcomes and damage the technology’s reputation. Diffusion varies by system: some systems have mandatory curriculum updates that drive adoption, while in other systems, peer competition and professional differentiation function as informal socialization mechanisms.

Block C—Trust, Human Oversight & Workflow: Trust is essential to reach routinization. EI15 said that trust is outcome-dependent and built through consistent, predictable surgical results across the initial deployment. After the implementation, reconfiguration need to extend beyond the surgical team to encompass the entire care network, including nurses and patient communication. Ongoing training across the surgical team is necessary. Transparency and explainability of systems’ decisions become critical if the clinical benefits margin between robotic and conventional surgery is small, as the perceived risk of the robotic option is intuitively higher. EI15 rejects the skill erosion hypothesis because hybrid human-robot workflows require a higher level of surgical competence, and the skills just develop.

Block D—Governance, Regulation & Institutionalization: Legal liability is an unresolved misalignment. Internal governance needs to promote system use, as adoption is often not self-evident to surgeons without institutional encouragement. A necessary precondition for EI15 is a baseline level of digital infrastructure in hospitals, such as electronic health records, to be able to integrate surgical robotic systems effectively.

Block E—Outlook: EI15 stated that hospitals without a semi-autonomous surgical robot risk falling behind technically. Important is the requirement of minimum case volume for surgeons, which is currently still an unresolved governance gap that has to be addressed to ensure competence-based routinization.

Appendix C: Procedure of the Qualitative Analysis

C.1 Coding Manual

1. Individual Factors

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
A - Individual	**A1 - Peformance Expectancy**	Statements referring to the perceived usefulness or expected benefits of SARS for the surgeon or OP personell	"You have more time because the AI handles the repetitive and sometimes tedious tasks...which directly impacts job satisfaction and may even help prevent burnout." (EI7)	Benefits or improvements are mentioned based on surgical robotic systems for the surgeon such as reduced overall workload	Benefits are not relatet to surgical robotic systems
	A2 - Effort Expectancy	Statements about the perceived cognitive effort, learning curve, or comlexity involved in operating the system	"When introducing new technology, you first have to go through a rough patch... 'Oh my God, I can do this better without the systems'. There is a learning curve. You have to manage that well; it's normal. No one should drop out." (EI7)	Descirbes difficulites in handling the system, time needed to master it or lack of intuitiveness of the interace	Abence of training infastructure or programs, system errors or failures
	A3 - Social Influence	Statements about the influence of colleagues, superiors,opinion leader, or professional communities on an individuals willingness to adopt the system	"If you have one or two senior residents who are passionate about the idea and can demonstrate it to their residents in the operating room...a picture is worth a thousand words...when you actually see that the senior resident can work more effectively with the help of these systems, it fosters openness." (EI7)	Someone describes how peers, department heads, medical associations, or early adopters shape attitude or decision to use the system	External competitive pressure between hospitals influencing investment decisions; Top-down management mandates
	A4 - Professional Identity / Skill Erosion	Statements about perceived threats to surgical professionalism, fear of deskilling, AI dependency, or changes to clinical judgment and decision-making authority	"There are top robotic surgeons, but if the robot malfunctions, they have to bring in another surgeon because they can no longer perform surgery at all—whether open or laparoscopic." (EI9)	Surgeons express concern about losing manual skills, becoming over-reliant on the system, losing decision-making sovereignty, or feeling their professional identity is at risk	General training needs; Trust in system capabilities
	A5 - Change Resistance	Statements about individual, professional, or cultural resistance to adopting new technologies	"The biggest hurdle is always the staff. The resilience of hospital staff is often underestimated. We've never done this before. Anyone could just show up. And we definitely won't do it that way." (EI1)	Describes reluctance or hesitation toward new technology based on habit, routine, or a preference for familiar methods, general scepticsm	Driven by organizational processes or institutional structures rather than individual or cultural attitude

2. Technical Factors

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
B - Technical	**B1 - Relative Advantage over Exisiting Systems**	Statements about measurable, evidence-based advantages of the system over conventional procedures, expressed in clinical outcomes, efficiency gains, or resource savings	"A surgeon who stands at the operating table for eight hours will eventually lose focus... but the machine works just as well in the first hour as it does in the 25th." (EI1)	Objective metrics are mentioned: reduced blood loss, shorter OR time, shorter hospital stays, fewer complications	A surgeon's subjective belief that the system is useful; Competitive positioning of a hospital
	B2 - Compatibility & Interoperability	Statements about the technical integration of the system into existing digital infrastructure, imaging platforms, hospital IT systems, or data standards	"Achieving true interoperability with existing systems is difficult and takes time." (EI7)	Someone discusses interface problems, lack of standardization, data exchange, or system compatibility with existing hardware	General IT infrastructure without direct system integration; data privacy legal requirements
	B3 - Technical Reliability & Maturity	Statements about system stability, fault tolerance, predictability of system behavior, and the current technological readiness level of AI functions	"A system that cannot be able to respond on time is going to be an unreliable system." (EI2)	Someone describes unexpected system actions, software failures, black-box behavior from a technical standpoint, or the developmental maturity of AI capabilities	Loss of surgeon trust due to black-box behavior from a personal trust perspective; Governance requirements for traceability

3. Organizational Facotrs

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
C - Organizational	**C1 - Management & Board Support**	Statements about the role of hospital leadership, boards, or senior physicians in approving investments, releasing resources, and providing institutional backing	"Management support is necessary since they are the once who decide to deploy the technology." (EI5)	Top-down commitment is mentioned, boards must approve budgets, or lack of leadership support is cited as a barrier to adoption	Peer influence among surgeons ;strategic sensing and investment decisions in dynamic adaptation context
	C2 - Financial Ressources	Statements about acquisition costs, maintenance costs, budget planning, and financial viability of the technology	"Cost effectiveness is a huge constraint for robotic surgical applications in the UK. It costs, I think, about 2 million or 3 million pounds for a robot. And there's also ongoing costs for that machine, maintenance costs and training costs and whatnot." (EI6)	High capital costs, difficult ROI calculation, lack of business case, financing models, or budget constraints are discussed	Reimbursement structures from external payers
	C3 - Tangible & Intangible Ressources	Statements about existing or missing resources, both material (hardware, computing systems, annotated datasets) and immaterial (tacit knowledge, OR routines, surgical expertise, experienced OR team)	„We have fewer medically trained staff, especially for the operating room." (EI3)	Missing data infrastructure for AI training, lack of team expertise, absent computing infrastructure, or the implicit knowledge of experienced OR nurses are mentioned as success factors	Reskilling and competence development as an ongoing dynamic process; infrastructure in relation to system integration
	C4 - Workflow Integration & Infrastructure	Statements about the need to adapt existing OR procedures, room scheduling, sterilization routines, or clinical processes to accommodate the technology	"Hospitals need to design new processes in order to ultimately integrate such systems into my workflow." (EI1)	Concrete logistical requirements in OR operations are described - whether already resolved or perceived as a barrier	Workflow adaptation as an ongoing reconfiguration process after adoption; IT system integration

4. Environmental Factors

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
D - Environmental	**D1 - Competitive Pressure**	Statements about external competitive pressure from other hospitals or the broader market environment	"Hospitals that fail to develop these capabilities naturally risk falling behind in the medium and long term." (EI7)	Hospital describes pressure to adopt because competing institutions already use the technology, when technology is framed as a competitive differentiator for patients or skilled staff, or when non-adoption is described as a medium- to long-term institutional risk	When internal pressure is meant; Peer influence on individual surgeons
	D2 - External Regulatory Context	Statements about EU-MDR, EU AI Act, national data protection laws, or state frameworks as an external condition acting as context for adoption	"And ever since MDR it's been incredibly difficult to get anything approved for in vivo use in the first place." (EI3)	Regulation is described as an external given, as an enabler or barrier to the adoption decision at market level	How the hospital internally deals with these requirements; Liability and accountability structures
	D3 - Reimbursement & Funding Models	Statements about DRG billing systems, missing reimbursement codes, insurance models, or external financial incentive structures as systemic conditions	„Robotic assisted procedures are not reimbursed, which means if you want a robot assisted procedure, you need to pay out of pocket." (EI10)	Missing billing options for robotic procedures, lack of incentive structures for investment, or external funding programs are mentioned	Hospital-internal ROI and budget planning

5. Routinization

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
E - Routinization	E1 - Sensing	Statements about the ability to identify and interpret new AI opportunities, technology trends, or emerging threats at an early stage	"If you see these techniques at conferences or similar events and think they might offer an advantage to your institution, you would take a critical look at them and then start a conversation with the people involved." (EI12)	Hospitals or managers describe how they monitor market changes, new system generations, or regulatory trends and use these for strategic decisions	Competitive pressure as an external given fact
	E2 - Seizing	Statements about concrete strategic investment decisions, contracting strategies, and resource commitments made after identifying an opportunity		Timing and quality of investment decisions, make-or-buy considerations, or governance designs for system implementation are discussed	Operational budget process without strategic orientation; External reimbursement incentives
	E3 - Transformation / Reconfiguation	Statements about the continuous adaptation of OR workflows, role profiles, training concepts, and data processes after implementation to enable and sustain routine use	„Implementation is one thing, but I believe the real work begins after that. Processes need to be adapted, workflows need to be integrated, and interfaces need to be optimized." (EI7)	Reskilling, new role profiles, changed coordination structures between OR and IT, feedback loops for AI training, or ongoing process adaptations are described	One-time workflow adaptation before or at implementation; Competence development as a static resource question
	E4 - Sub-phase of Routinization	Statements explicitly describing the transition between phases, or the distinguishing characteristics between pilot/first use and genuine routine use	"Routinization describes the state in which technology has truly become an integral part of everyday clinical practice...the technology is no longer questioned at all, but is seamlessly integrated into processes, scalable, and usable independently of individual users." (EI7)	Someone defines routine use, describes when a technology "is no longer seen as new," distinguishes between showcase projects and daily operations, or discusses the DOI adoption curve	Concrete measures to achieve routinization; External market diffusion speed

6. Trust

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
F - Trust	F1 - Ability	Trust based on the perceived technical competence, precision, and functional reliability of the system	"Surgeons trust is essential. If they don't trust that the robots work better or work properly, then it's all over." (EI3)	Surgeons or patients say they trust the system because it works precisely, produces no unexpected movements, or functions consistently	Objective system reliability from a technical engineering perspective
	F2 - Benevolence	Trust based on the belief that the system acts in the best interest of the patient and prioritizes patient safety	"This is about patients and patient safety, and that is our guiding principle...the starting point." (EI7)	Statements about whether the system "is on the right side," protects patients, or prioritizes safety mechanisms	Concrete safety protocols and governance rules
	F3 - Integrity / Explainability	Trust based on the comprehensibility and rule-conformity of system behavior - explainable AI from the user's perspective; or transparency need in the process	"A common reason why colleagues are hesitant is a lack of transparency...especially when it comes to AI systems. That brings us to the issue of the 'black box' and trustworthy AI." (EI7)	Surgeons demand transparent decision processes, describe the black-box problem as a trust barrier, or cite explainable AI as a foundation for trust; transparent communication	System-side explainability as a technical property; Accountability requirements from a governance perspective
	F4 - Trust Calibration	Statements about the dynamic process of trust adjustment,and overreliance and under-reliance and their consequences	"They were sued because the system is too easy to use. The surgical staff feels too confident too soon." (EI8)	Someone describes trust declining after system errors, surgeons trusting the system too much and reducing their own oversight, or the need to train trust calibration explicitly	Fundamental willingness to trust; System failure as a technical problem
	F5 - Patient Trust	Statements about trust formation among patients: safety perception, communication about autonomy level, informed consent, and patient misunderstandings about system autonom	"Many patients either feel enthusiastic about it, or it actually leads them to reject it because they say they're afraid... they don't trust that the robot might suddenly start acting on its own." (EI5)	Patient concerns, informed consent for autonomous functions, transparent communication about shared decision-making, or societal acceptance are discussed	Surgeon trust; Ethical governance requirements
	F0 - General Trust	Trust as an overarching, unspecified principle of adoption – a fundamental normative statement without reference to a specific dimension of trust	„Healthcare is a business of trust...Trust as an overarching, unspecified principle of adoption – a fundamental normative statement without reference to a specific dimension of trust." (EI7)	Use when trust is named as a general prerequisite for adoption or routinization without specifying what kind of trust, in what, or from whose perspective	Do not use when a specific trust dimension (F1–F5) is clearly identifiable in the statement

7- Governance & Regulation

Category	Subcategory	Definition	Anchor Example	Coding Rule (Use when…)	Exclusion Role (Use not when…)
G - Governance & Regulation	G1 - Accountability	Statements about the traceability of AI-supported decisions, documentation obligations, and institutional mechanisms for decision auditability	"How on earth am I supposed to audit an AI?...Now that I think about it, that would certainly be a challenge." (EI1)	The black-box problem is discussed from a governance perspective, audit trails, certification requirements, or reporting obligations to authorities are mentioned	XAI demand from the surgeon's personal trust perspective; Technical system transparency
	G2 - Liability Allocation	Statements about the distribution of civil liability and criminal responsibility in the event of system errors or adverse surgical outcomes	„Who is responsible if a semi-autonomous system makes an error? Would it be the surgeon? Would it be the hospital? Would it be the manufacturer of the robot?" (EI6)	The question "Who is liable if the robot makes a mistake?" is discussed, for the surgeon, manufacturer, hospital, or software developer	General regulatory environment; Internal role clarification without liability dimension
	G3 - Clinical Governance Structures	Statements about hospital-internal rule frameworks, role definitions in the OR team, ethical oversight committees, certification pathways, and clinical protocols for semi-autonomous systems	"Internally, we establish very clear SOPs for everything - procedures, training structures, and so on... There's an SOP with illustrations showing how to position the patient and the steps of the surgery... A very high level of standardization is crucial, as is extensive training for all involved disciplines." (EI12)	Internal SOPs, competency frameworks, simulation requirements, ethics review boards, or role boundaries between surgeon, AI, and OR staff are described	External regulation; Dynamic role adaptation in the reconfiguration proces
	G4 - Data Privacy & Cybersecurtiy	Statements about GDPR compliance, cybersecurity requirements, secondary use of surgical data for AI training, and protection of critical clinical systems against unauthorized access	" I see privacy concerns and data protection requirements. Because if you want to achieve a certain degree of autonomy or partial autonomy, you'll need patient data for that - meaning individualized data - and you'd probably have to stream that data to a manufacturer or an automated platform. That's going to be a problem." (EI12)	Data security, access rights, anonymization requirements, protection against hacking, or regulatory requirements for data storage are concretely addressed	Technical system architecture for data processing, General data privacy as external regulatory landscape

C.2 Excel Coding Section

Interview ID	Interviewee Group	Question Block	Direct Quotations	Category	Subcategory	Memo / Interpretation
EI1	MedTech	A	"the problem is less about the willingness of the staff and more about funding options. The funding option are rather limited at the moment"	D	D3 - Reimbursement & Funding Models	Financing as a problem not the willingness of staff
EI1	MedTech	A	"there are university hospitals that receive grants and the like. That's where you find these early adopters. And ultimately, widespread adoption won't be possible without these early adopters, who publish their findings in scientific studies"	A	A3 - Social Influence	Early adopters are important
EI1	MedTech	A	"These university hospitals, which have already adopted the technology, are exerting a significant influence through publications and conference presentations, motivating other doctors to try the method as well."	A	A3 - Social Influence	early adopters influence colleagues
EI1	MedTech	A	"Whether it ultimately gains widespread acceptance depends, in the end, on reimbursement and the financial performance"	D	D3 - Reimbursement & Funding Models	Reimbursement structure as a key prerequisite for routinization
EI1	MedTech	A	"Because a system that costs a lot of money but doesn't generate any revenue will very quickly end up gathering dust."	C	C2 - Financial Resources	lack of internal economic viability leads to underutilization
EI1	MedTech	B	"Hospitals first needs the right staff to support this initiative, because it's always difficult to push something through against the staff's wishes."	A	A5 - Change Resistance	acceptance of staff as intangible reosurce
EI1	MedTech	B	"a relatively small operating room where I need to bring in a large piece of equipment, that can be quite a challenge."	C	C4 - Workflow Integration & Infrastructure	operation room infrastructure as a physical barrier -- large technology vs. Small rooms
EI1	MedTech	B	"Hospitals need to design new processes in order to ultimately integrate such systems into my workflow."	C	C4 - Workflow Integration & Infrastructure	Process adaptation as a prerequisite for integration
EI1	MedTech	B	"It's all about the numbers. It's about economic success, because the hospital director will say quite plainly, 'Okay, this brings us money, or this costs us money.'"	C	C2 - Financial Resources	focus is on internal economic evaluation, budgetary logic, and financial viability within the hospital.
EI1	MedTech	B	"Ultimately, implementing such a system is a unique selling point...and it allows me to attract more patients."	D	D1 - Copetitive Pressure & External Cooperation	Technology as a competitive differentiator and an attractor for more patients
EI1	MedTech	B	"Data protection and cypersecurity is a huge bottleneck that hospitals face since germany follows strict interpretation. As specially if they are locked to international sources"	G	G4 - Data Protection & Cybersecurity	Internatinal data sources as a risk in data protection; cybersecurity as a problem
EI1	MedTech	B	"surgical robots collect and process large amounts of sensitive patient data in order to function properly, which raises privacy issues"	G	G4 - Data Protection & Cybersecurity	Sensitive data barrier
EI1	MedTech	B	"What logistical arrangements do I need to make regarding purchasing, consumables, and so on, since these will change as a result of the implementation?"	C	C3 - Tangible & Intangible Resources	Changes in Purchasing and Logistics

C.3 Category Frequency

Frequency Distribution of Deductive Categories and Subcategories

1. Individual Factors

Category	Frequency	Subcategory	Frequency
A - Individual	94	A1 - Peformance Expectancy	20
		A2 - Effort Expectancy	14
		A3 - Social Influence	23
		A4 - Professional Identity / Skill Erosion	19
		A5 - Change Resistance	18

2. Technical Factors

Category	Frequency	Subcategory	Frequency
B - Technical	52	B1 - Relative Advantage over Exisiting Systems	29
		B2 - Compatibility & Interoperability	12
		B3 - Technical Reliability & Maturity	11

3. Organizational Factors

Category	Frequency	Subcategory	Frequency
C - Organizational	131	C1 - Management & Board Support	15
		C2 - Financial Ressources	29
		C3 - Tangible & Intangible Ressources	57
		C4 - Workflow Integration & Infrastructure	30

4. Environmental Factors

Category	Frequency	Subcategory	Frequency
D - Environmental	75	D1 - Competitive Pressure	24
		D2 - External Regulatory Context	33
		D3 - Reimbursement & Funding Models	18

5. Routinization

Category	Frequency	Subcategory	Frequency
E - Routinization	74	E1 - Sensing	1
		E2 - Seizing	
		E3 - Transformation / Reconfiguation	47
		E4 - Sub-phase of Routinization	26

6. Trust

Category	Frequency	Subcategory	Frequency
F - Trust	73	F1 - Ability	10
		F2 - Benevolence	2
		F3 - Integrity / Explainability	12
		F4 - Trust Calibration	21
		F5 - Patient Trust	25
		F0 - general trust	3

7. Governance & Regulation

Category	Frequency	Subcategory	Frequency
G - Governance & Regulation	51	G1 - Accountability	3
		G2 - Liability Allocation	12
		G3 - Clinical Governance Structures	17
		G4 - Data Privacy & Cybersecurtiy	19

Frequency Distribution of Categories Across Stakeholder Groups

Expert Group	Category	Frequency	Subcategory	Frequency
MedTech	A - Individual	47	A1 - Peformance Expectancy	8
			A2 - Effort Expectancy	8
			A3 - Social Influence	15
			A4 - Professional Identity / Skill Erosion	6
			A5 - Change Resistance	10
	B - Technical	33	B1 - Relative Advantage over Exisiting Systems	18
			B2 - Compatibility & Interoperability	8
			B3 - Technical Reliability & Maturity	7
	C - Organizational	65	C1 - Management & Board Support	8
			C2 - Financial Ressources	17
			C3 - Tangible & Intangible Ressources	26
			C4 - Workflow Integration & Infrastructure	14
	D - Environmental	44	D1 - Competitive Pressure	14
			D2 - External Regulatory Context	21
			D3 - Reimbursement & Funding Models	9
	E - Routinization	47	E1 - Sensing	0
			E2 - Seizing	0
			E3 - Transformation / Reconfiguation	29
			E4 - Sub-phase of Routinization	18
	F - Trust	39	F1 - Ability	5
			F2 - Benevolence	1
			F3 - Integrity / Explainability	7
			F4 - Trust Calibration	13
			F5 - Patient Trust	10
			F0 - general trust	3
	G - Governance & Regulation	16	G1 - Accountability	2
			G2 - Liability Allocation	2
			G3 - Clinical Governance Structures	2
			G4 - Data Privacy & Cybersecurtiy	10

Expert Group	Category	Frequency	Subcategory	Frequency
Physician	A - Individual	33	A1 - Peformance Expectancy	9
			A2 - Effort Expectancy	5
			A3 - Social Influence	5
			A4 - Professional Identity / Skill Erosion	7
			A5 - Change Resistance	7
	B - Technical	11	B1 - Relative Advantage over Exisiting Systems	8
			B2 - Compatibility & Interoperability	1
			B3 - Technical Reliability & Maturity	2
	C - Organizational	50	C1 - Management & Board Support	5
			C2 - Financial Ressources	8
			C3 - Tangible & Intangible Ressources	24
			C4 - Workflow Integration & Infrastructure	13
	D - Environmental	19	D1 - Competitive Pressure	8
			D2 - External Regulatory Context	5
			D3 - Reimbursement & Funding Models	6
	E - Routinization	15	E1 - Sensing	1
			E2 - Seizing	0
			E3 - Transformation / Reconfiguation	10
			E4 - Sub-phase of Routinization	4
	F - Trust	21	F1 - Ability	0
			F2 - Benevolence	2
			F3 - Integrity / Explainability	1
			F4 - Trust Calibration	2
			F5 - Patient Trust	3
			F0 - general trust	13
	G - Governance & Regulation	25	G1 - Accountability	1
			G2 - Liability Allocation	9
			G3 - Clinical Governance Structures	10
			G4 - Data Privacy & Cybersecurtiy	5

Expert Group	Category	Frequency	Subcategory	Frequency
Researcher	A - Individual	14	A1 - Peformance Expectancy	3
			A2 - Effort Expectancy	1
			A3 - Social Influence	3
			A4 - Professional Identity / Skill Erosion	6
			A5 - Change Resistance	1
	B - Technical	8	B1 - Relative Advantage over Exisiting Systems	3
			B2 - Compatibility & Interoperability	3
			B3 - Technical Reliability & Maturity	2
	C - Organizational	16	C1 - Management & Board Support	2
			C2 - Financial Ressources	4
			C3 - Tangible & Intangible Ressources	7
			C4 - Workflow Integration & Infrastructure	3
	D - Environmental	12	D1 - Competitive Pressure	2
			D2 - External Regulatory Context	7
			D3 - Reimbursement & Funding Models	3
	E - Routinization	12	E1 - Sensing	0
			E2 - Seizing	0
			E3 - Transformation / Reconfiguation	8
			E4 - Sub-phase of Routinization	4
	F - Trust	13	F1 - Ability	3
			F2 - Benevolence	0
			F3 - Integrity / Explainability	3
			F4 - Trust Calibration	5
			F5 - Patient Trust	2
			F0 - general trust	0
	G - Governance & Regulation	10	G1 - Accountability	0
			G2 - Liability Allocation	1
			G3 - Clinical Governance Structures	5
			G4 - Data Privacy & Cybersecurtiy	4

Expert Coverage per Subcategory

Expert Group	Category	Subcategory	X/15	Interviewees	Expertgroup
All Experts	A - Individual	A1 - Peformance Expectancy	12	EI1, EI4, EI5, EI6, EI7, EI8, EI9, EI10, EI11, EI12, EI13, EI14	all
		A2 - Effort Expectancy	10	EI1, EI3, Ei4, Ei5, EI6, EI7, EI8, EI10, EI11, EI15	MedTech, Physician
		A3 - Social Influence	12	EI1, EI2, EI3, EI5, EI6, EI7, EI8, EI9, EI11, EI12, EI13, EI15	all
		A4 - Professional Identity / Skill Erosion	12	EI1, EI2, EI4, EI5, EI6, EI7, EI8, EI9, EI11, EI13, EI14, EI15	all
		A5 - Change Resistance	10	EI1, EI2, EI5, EI6, EI8, EI10, EI11, EI12, EI13, EI14	all
	B - Technical	B1 - Relative Advantage over Exisiting Systems	14	EI1, EI2, EI3, EI4, EI5, EI6, EI7, EI8, EI10, EI1, EI12, EI13, EI14, EI15	all
		B2 - Compatibility & Interoperability	7	EI3, EI7, EI8, EI9, EI10, EI13, EI14	all
		B3 - Technical Reliability & Maturity	7	EI1, EI2, EI3, EI5, EI11, EI13, EI14	all
	C - Organizational	C1 - Management & Board Support	8	EI3, EI5, EI6, EI7, EI12, EI3, EI14, EI15	all
		C2 - Financial Ressources	14	EI1, EI2, EI3, EI4, EI5, EI6, EI7, EI8, EI9, EI10, EI11, EI12, EI13, EI14	all
		C3 - Tangible & Intangible Ressources	15	all	all
		C4 - Workflow Integration & Infrastructure	12	EI1, EI3, EI4, EI5, EI6, EI7, EI8, EI9, EI10, EI11, EI13, Ei14	all
	D - Environmental	D1 - Competitive Pressure	11	EI1, EI2, EI5, EI6, EI7, EI8, EI9, EI11, EI12, EI13, EI14	all
		D2 - Regulatory Environment & Government Policy	12	EI1, EI2, EI3, EI6, EI7, EI8, EI10, EI11, EI12, EI13, EI14, EI15	all
		D3 - Reimbursement & Funding Models	11	EI1, EI3, EI6, EI7, EI8, EI9, EI10, EI11, EI12, EI14, EI15	all
	E - Routinization	E1 - Sensing	1	EI12	Physician
		E2 - Seizing	0		
		E3 - Transformation / Reconfiguation	14	EI1, EI2, EI3, EI5, EI6, EI7, EI8, EI9, EI10, EI11, EI12, EI13, EI14, EI15	all
		E4 - Sub-phase of Routinization	13	EI2, EI3, EI4, EI5, EI7, EI8, EI9, EI10, EI11, EI12, EI13, EI14, EI15	all
	F - Trust	F1 - Ability	6	EI3, EI6, EI7, EI8, EI13, EI15	all
		F2 - Benevolence	2	EI6, EI7	MedTech, Physician
		F3 - Integrity / Explainability	8	Ei1, EI6, EI7, EI8, EI9, EI12, EI13, EI15	all
		F4 - Trust Calibration	9	EI1, EI3, EI5, EI8, EI9, EI10, EI11, EI13, EI15	all
		F5 - Patient Trust	10	EI1, EI2, EI5, EI6, EI8, EI9, EI11, EI12, EI13, EI14	all
		F0 - general trust	2	EI7, EI10	MedTech
	G - Governance & Regulation	G1 - Accountability	3	EI1, EI3, EI12	MedTech, Physician
		G2 - Liability Allocation	7	EI1, EI4L EI6, EI8, EI12, EI14, EI15	all
		G3 - Clinical Governance Structures	9	EI1, EI5, EI6, EI7, EI9, EI12, EI13, EI14, EI15	all
		G4 - Data Privacy & Cybersecurtiy	11	EI1, EI2, EI3, EI6, EI7L EI8, EI9, EI11, EI12, EI13, EI14	all

Appendix D: Online Survey Outline

Construct	Question Nr.	Question	Measurement	Answer possibility
Imagine you need a knee operation due to an injury. There is the possibility to be operated with a semi-autonomous surgical robotic system. Please answer the following question honestly.				
Prior Knowledge	Q3	Who is primarily responsible for making decisions during surgery involving a semi-autonomous surgical robotic system?	Multiple Choice	○ The robot itself ○ An AI that makes decisions and simply informs the doctor ○ The surgeon who operates and controls the robot ← correct ○ I have no idea
	Q4	Which of the following best describes a semi-autonomous surgical robotic system used in the operating room?	Multiple Choice	○ Human-like android ○ Arm system with camera/ instruments <- correct ○ A large computer screen ○ No idea
	Q5	A semi-autonomous surgical robotic system can support specific surgical actions, but the surgeon remains responsible for the procedure.	False/Right Question	○ Yes ○ No
	Q6	During semi-autonomous robotic surgery, the robot takes the lead while the surgeon mainly monitors the procedure.	False/Right Question	○ Yes ○ No
	Q7	During semi-autonomous robotic surgery, the surgeon has less control over the procedure than during conventional surgery.	False/Right Question	○ Yes ○ No
Explanation **A semi-autonomous surgical robot is a medical assistance system that supports a surgeon during operations. For example, the system enables more precise incisions, more stable camera control, or the execution of smaller individual surgical steps with greater accuracy.** **Important: The surgeon retains complete control throughout the entire procedure. The surgeon actively controls the system, makes all medical decisions, and can intervene manually at any time or stop the robot immediately. The robot does not operate independently.**				
Pereceived Benefit	Q9-1	I expect faster recovery when semi-autonomous surgical robotic systems are used.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q9-2	I expect lower complication rates when semi-autonomous surgical robotic systems are used.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q9-3	I expect better surgical outcomes when semi-autonomous surgical robotic systems are used.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q9-4	I expect higher surgical precision when semi-autonomous surgical robotic systems are used.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
Doctor Recommendation	Q10_1	I trust the recommendations for a semi-autonomous surgical robotic procedure from my doctor.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q10_2	The opinion of my doctor is important to me when I think about the use of semi-autonomous surgical robotic systems.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q10_3	I follow the advices of my doctor.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q10_4	If my doctor recommended the use of a semi-autonomous surgical robotic system, I take this recommendation seriously.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
Peer Influence	Q11_1	The opinion of family and friends influence my medical decisions.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q11_2	My family and friends support the use of semi-autonomous surgical robotic systems.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q11_3	The views of my family and friends are important to me when I think about new medical technologies.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
Control Question	Q12	If you are reading this, please cklick "50"	Multiple Choice	Scale form 1 - 100
Trust in Medical Technology	Q13_1	New medical technologies are reliable.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q13_2	I am confident in new medical technologies.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q13_3	I can trust new medical technologies.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q13_4	I am suspicious of the new medical technology outputs.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
Trust in Vaccines	Q13_5	I trust vaccines against diseases.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q13_6	I am confident in the safety of vaccines	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q13_7	I am confident in the science behind vaccines	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
Data Privacy Concerns	Q14_1	I am concerned about my privacy when semi-autonomous surgical robotic systems are used during surgery.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q14_2	The use of semi-autonomous surgical robots could lead to problems with protection of my personal health data.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q14_3	Data protection is an important factor for me when I consider the use of semi-autonomous surgical robots.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q14_4	I am concerned that unauthorized individuals could access my health data when semi-autonomous surgical robots are used.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q14_5	I am concerned that my health data is not stored or transmitted securely enough when semi-autonomous surgical robots are used.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
Quality Orientation	Q15_1	In your opinion, what do you think is the main focus when using semi-autonomous surgical robots?	Scale (1-100)	0 = Cost Efficiency 100 = Quality Improvement
Acceptance	Q16_1	I accept semi-autonomous robot-assisted surgery if offered to me.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q16_2	semi-autonomous robot-assisted surgery would be a good option.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q16_3	I am positive toward the use of semi-autonomous surgical robotic systems in surgery.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree
	Q16_4	Overall, I support the use of semi-autonomous surgical robotic systems in appropriate surgical situations.	7 point Likert-Scale	1 = Strongly disagree 7 = Strongly agree

Demographics	Q17	Have you ever undergone surgery before?	Multiple Choice	○ Yes ○ No ○ Prefer not to say
	Q18_1	If yes what type of surgery	Dental	
	Q18_2		Neuro	
	Q18_3		Cardiothoracic	
	Q18_4		Gynecology	
	Q18_5		Urological	
	Q18_6		Eye ear nose	
	Q18_7		Plastic; dermatologic	
	Q18_8		Orthopedic	
	Q18_9		Others	
	Q19	Do you currently work, or have you previously worked, in the healthcare sector?	Multiple Choice	○ Yes ○ No ○ Prefer not to say
	Q20	How would you rank the general health status in your country?	Multiple Choice	○ Excellent ○ Very good ○ Fair ○ Poor ○ Very poor
	Q21	what is your current health insurance status?	Multiple Choice	○ Government-provided / publicly funded coverage ○ Private health insurance ○ Both government-provided and private coverage ○ Employer-provided health coverage ○ Other form of health coverage ○ None ○ Prefer not to say
	Q22	What is your age?	Field (self-filling)	Answer Field
	Q23	What is your gender?	Multiple Choice	○ Female ○ Male ○ Diverse ○ Prefer not to say
	Q24	What is your highest education level?	Multiple Choice	○ Doctoral degree / PhD ○ Master's degree ○ Bachelor's degree ○ Secondary school / high school ○ Vocational training / apprenticeship ○ Other ○ Prefer not to say
	Q25	Where are you currrently living?	Multiple Choice	Dropdown menu (every country)

Appendix E: Quantitative Statistics

E.1 Reliability Analysis

Reliability Analysis

Scale: Perceived Benefit

Reliability Statistics

Cronbach's Alpha	N of Items
0,828	4

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
When semi-autonomous surgical robotic systems are used... - I expect a faster recovery.	16,14	11,068	0,529	0,861
Please indicate to what extent you agree or disagree with the following statements. When semi-autonomous surgical robotic systems are used... - I expect lower complication rates.	15,00	11,167	0,729	0,750
When semi-autonomous surgical robotic systems are used... - I expect better surgical outcomes.	14,91	11,590	0,745	0,747
Please indicate to what extent you agree or disagree with the following statements. When semi-autonomous surgical robotic systems are used... - I expect higher surgical precision.	14,39	12,419	0,678	0,779

Scale: Doctor Recommendation

Reliability Statistics

Cronbach's Alpha	N of Items
0,710	4

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
- I trust my doctor's recommendations for a semi-autonomous surgical robotic procedure.	17,56	3,993	0,477	0,661
- The opinion of my doctor is important to me when I think about the use of semi-autonomous surgical robotic systems.	17,14	4,627	0,439	0,680
- I follow my doctor's advice.	17,59	3,983	0,477	0,662
- If my doctor recommended an operation with a semi-autonomous surgical robotic system, I take this recommendation seriously.	17,38	4,029	0,611	0,581

Scale: Peer Influence

Reliability Statistics

Cronbach's Alpha	N of Items
0,638	3

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
- The opinion of family and friends influences my medical decisions.	9,97	4,423	0,602	0,315
- My family and friends support the use of minimal invasive surgery.	9,77	6,806	0,192	0,834
- The views of my family and friends are important to me when I think about new medical technologies.	10,10	3,887	0,607	0,284

Scale: Trust in Medical Technologies

Reliability Statistics

Cronbach's Alpha	N of Items
0,785	4

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
- New medical technologies are reliable.	15,34	8,131	0,616	0,730
- I am confident in new medical technologies.	15,15	7,861	0,720	0,690
- I can trust new medical technologies.	15,33	7,073	0,724	0,668
- I am suspicious of the new medical technology outputs.	16,22	6,537	0,455	0,858

Scale: Trust in Vaccines

Reliability Statistics

Cronbach's Alpha	N of Items
0,941	3

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
- I trust vaccines against infectious diseases.	11,44	5,658	0,870	0,920
- I am confident in the safety of vaccines.	11,70	5,305	0,899	0,898
- I am confident in the science behind vaccines.	11,54	5,879	0,867	0,923

Scale: Data Privacy Concerns

Reliability Statistics

Cronbach's Alpha	N of Items
0,878	5

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
- I am concerned about my privacy when semi-autonomous surgical robotic systems are used during surgery.	12,42	29,544	0,714	0,853
- The use of semi-autonomous surgical robots could lead to problems with the protection of my personal health data.	12,01	28,297	0,704	0,852
- Data protection is an important factor for me when I consider the use of semi-autonomous surgical robots.	11,30	27,043	0,579	0,892
- I am concerned that unauthorized individuals could access my health data when semi-autonomous surgical robots are used.	11,89	26,681	0,803	0,829
- I am concerned that my health data is not stored or transmitted securely enough when semi-autonomous surgical robots are used.	11,81	26,787	0,797	0,830

Scale: Acceptance

Reliability Statistics

Cronbach's Alpha	N of Items
0,908	4

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
- I accept semi-autonomous robot-assisted surgery if offered to me.	16,94	6,996	0,780	0,885
- Semi-autonomous robot-assisted surgery would be a good option.	16,85	7,162	0,813	0,874
- I am positive toward the use of semi-autonomous surgical robotic systems in surgery.	16,85	6,727	0,816	0,872
- Overall, I support the use of semi-autonomous surgical robotic systems in appropriate surgical situations.	16,57	7,259	0,761	0,892

E.2 Model 1: Normal Linear Regression

Model 1 (REGRESSION)	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	t	Sig.	Collinearity Statistics VIF
Intercept	1,067	0,445	2,399	0,017	
Quality orientation	0,002	0,001	1,233	0,219	1,091
Prior knowledge	0,084	0,037	2,290	0,023	1,182
Perceived benefit	0,214	0,034	6,269	0,000	1,299
Doc. recommendation	0,272	0,062	4,392	0,000	1,449
Peer influence	0,024	0,027	0,891	0,373	1,158
Trust in MT	0,320	0,050	6,432	0,000	1,619
Trust in Vaccines	0,036	0,033	1,104	0,270	1,235
Data privacy concerns	-0,097	0,029	-3,386	0,001	1,234
Perc. healthcare quality	-0,063	0,048	-1,305	0,193	1,179
Age	-0,003	0,002	-1,409	0,160	1,318
Gender male	0,044	0,075	0,586	0,559	1,142
Healthcare experience = yes	0,102	0,097	1,048	0,295	1,133
Surgery experience = yes	0,169	0,076	2,221	0,027	1,229
Additional private coverage = yes	0,023	0,099	0,233	0,816	1,087
Private health insurance = yes	-0,124	0,087	-1,424	0,156	1,088

Dependent Variable: Acceptance

R Square	Adjusted R Square	Std. Error of the Estimate
0,568	0,544	0,56817

Note. $N = 292$. The dependent variable is acceptance. P-values < .05 indicated statistical significance.

E.3 Correlation Table

Correlations

		Age	Quality Orientation	Prior Knowledge	Perceived Benefit	Doctor Recommendation	Peer Influence	Trust in MT	Trust in Vaccines	Data Privacy Concerns
Quality Orientation	Pearson Correlation	-0,104								
	Sig. (2-tailed)	0,076								
	N	292								
Prior Knowledge	Pearson Correlation	0,054	.127*							
	Sig. (2-tailed)	0,343	0,030							
	N	305	292							
Perceived Benefit	Pearson Correlation	0,055	.185**	.173**						
	Sig. (2-tailed)	0,335	0,002	0,002						
	N	305	292	305						
Doctor Recommendation	Pearson Correlation	-0,024	.144*	.238**	.295**					
	Sig. (2-tailed)	0,675	0,014	0,000	0,000					
	N	305	292	305	305					
Peer Influence	Pearson Correlation	-0,106	0,028	-0,098	.145*	0,035				
	Sig. (2-tailed)	0,066	0,629	0,086	0,011	0,548				
	N	305	292	305	305	305				
Trust in MT	Pearson Correlation	0,057	.141*	.169**	.326**	.448**	-0,020			
	Sig. (2-tailed)	0,320	0,016	0,003	0,000	0,000	0,723			
	N	305	292	305	305	305	305			
Trust in Vaccines	Pearson Correlation	-.216**	-0,006	0,024	0,100	.293**	-0,061	.349**		
	Sig. (2-tailed)	0,000	0,923	0,672	0,082	0,000	0,287	0,000		
	N	305	292	305	305	305	305	305		
Data Privacy Concerns	Pearson Correlation	0,102	-0,077	-.209**	-.150**	-.271**	0,106	-.378**	-.178**	
	Sig. (2-tailed)	0,075	0,188	0,000	0,009	0,000	0,064	0,000	0,002	
	N	305	292	305	305	305	305	305	305	
Acceptance	Pearson Correlation	-0,012	.219**	.286**	.501**	.538**	0,017	.586**	.288**	-.411**
	Sig. (2-tailed)	0,832	0,000	0,000	0,000	0,000	0,767	0,000	0,000	0,000
	N	305	292	305	305	305	305	305	305	305

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

E.4 Paired Samples t-Test between Trust in MT vs. Trust in Vaccines

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Trust in MT - Trust in Vaccines	-0,58989	1,20212	0,06883	-0,72534	-0,45444	-8,570	304	0,000

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Trust in MT	5,1773	305	0,87570	0,05014
	Trust in Vaccines	5,7672	305	1,18381	0,06778

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Trust in MT & Trust in Vaccines	305	0,349	0,000

Paired Samples Effect Sizes

					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
Pair 1	Trust in MT - Trust in Vaccines	Cohen's d	1,20212	-0,491	-0,609	-0,372
		Hedges' correction	1,20360	-0,490	-0,608	-0,371

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

Appendix F: Declaration of AI Use

In this master's thesis, selected AI tools were used to support various steps of the research and writing process. The tools used include Claude, Chat-GPT, Perplexity, NotebookLM, and Zotero. Claude, Chat-GPT, NotebookLM, and Perplexity helped with idea development, the structuring of the literature background, language refinement, improvement of clarity, and overall coherence of the text. It is important to mention that all papers were selected and reviewed by the author.

Additionally, Claude helped throughout the data cleaning and analysis process in SPSS, particularly to help locate relevant functions within the software. AI tools supported the identification of connections within the interviews and between interviews and the survey. However, the actual coding, analysis, interpretation, and formulation of the discussion were conducted by the author. Chat-GPT was also used to help summarize the interviews for the appendix.

Zotero was utilized as a reference management tool to organize the literature and assist with citations in accordance with APA 7th. It gave a structured space to collect, sort, and efficiently integrate references into the thesis.

To support the writing and overcome language barriers, DeepL Translate, DeepLWrite, and Grammarly were used. These tools were utilized to improve linguistic accuracy, readability, and the overall fluency of the text.

Very important, AI tools were not used to replace independent thinking, data collection, or the critical interpretation of results. All AI suggestions were reviewed, critically questioned, and verified by the author.