Leading Innovation in the Operating Room: Managing the Introduction of Robotic Surgery in Portuguese Hospitals

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Dissertation submitted in partial fulfilment of requirements for the MSc in Business, at the Universidade Católica Portuguesa, 5 January 2026

ABSTRACT

English

After lagging behind the United States and Japan, robotic-assisted surgery is now expanding rapidly across European health systems, yet its optimised use and integration remain uneven and frequently misaligned with governance, training and organisational capacity. Portugal mirrors this trend, with a random adoption trajectory that raises concerns regarding sustainability, equity and long-term strategic planning. This dissertation examines the adoption of robotic-assisted surgery in Portugal through a multilevel sociotechnical perspective, drawing on semi-structured interviews with 18 participants, including clinicians, hospital managers, industry representatives and international experts. Thematic analysis was used to explore how perceptions, organisational conditions and policy environments shape the current and future role of robotic surgery.

Findings show broad agreement regarding the clinical potential of robotic systems, particularly in ergonomics, precision and opportunities for innovation. Nevertheless, stakeholders also identify substantial challenges, including inconsistent training pathways, variable institutional readiness, fragmented governance mechanisms and the absence of a coordinated national strategy covering public and private facilities. Divergent priorities across stakeholder groups further contribute to a fragmented adoption landscape. To address these gaps, the study introduces a conceptual framework integrating micro, meso and macro determinants, emphasising the interdependencies required for safe, sustainable and ethically aligned implementation.

The dissertation offers empirical, theoretical and practical contributions, culminating in recommendations for policymakers, hospital leaders, training bodies and industry partners. In sum, the findings highlight that the successful expansion of robotic-assisted surgery in Portugal depends not only on technological capability but on coherent governance, strategic planning and responsible stewardship.

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Keywords: robotic-assisted surgery; sociotechnical systems; technology adoption; organisational readiness; innovation governance; Portugal; healthcare policy; surgical training; ethical implementation

Português

Após um período de atraso relativamente aos Estados Unidos e ao Japão, a cirurgia robótica está atualmente a expandir-se nos sistemas de saúde europeus; contudo, a sua integração permanece desigual e frequentemente desalinhada com as estruturas de governação, formação e capacidade organizacional. Portugal reflete esta tendência, apresentando uma trajetória de adoção fragmentada que levanta preocupações quanto à sustentabilidade, à equidade e ao planeamento estratégico.

Esta dissertação analisa a adoção da cirurgia robótica em Portugal a partir de uma perspetiva sociotécnica multinível, com base em entrevistas semiestruturadas realizadas a 18 participantes, incluindo clínicos, gestores hospitalares e representantes da indústria. A análise temática foi utilizada para explorar de que forma perceções individuais, condições organizacionais e enquadramentos políticos moldam o papel atual e futuro da cirurgia robótica. Os resultados revelam um consenso quanto ao potencial clínico dos sistemas robóticos, nomeadamente em termos de ergonomia, precisão e inovação. Contudo, os participantes identificam desafios relevantes, incluindo percursos formativos inconsistentes, níveis variáveis de prontidão institucional, mecanismos de governação fragmentados e a ausência de uma estratégia nacional coordenada que integre os setores público e privado. Divergências entre grupos de envolvidos contribuem para um panorama de adoção desigual.

Para responder a estas lacunas, o estudo propõe um modelo conceptual que integra determinantes aos níveis micro, meso e macro, enfatizando as interdependências necessárias para uma implementação segura, sustentável e eticamente alinhada. Os resultados evidenciam que o sucesso da cirurgia robótica em Portugal depende não apenas da capacidade tecnológica, mas também de governação coerente, planeamento estratégico e gestão responsável.

Título: Liderar a Inovação no Bloco Operatório: Gestão da Introdução da Cirurgia Robótica nos Hospitais Portugueses

Autor: Filipa de Oliveira Dias Gonçalves

Palavras-chave: cirurgia robótica; sistemas sociotécnicos; adoção tecnológica; prontidão organizacional; governação da inovação; Portugal; política de saúde; formação cirúrgica; implementação ética

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the support, generosity and encouragement of many people.

I would first like to thank my supervisor, Prof. Dr. Henrique Martins, for his thoughtful guidance, expertise and patience throughout this process. His feedback consistently refined the quality, clarity and ambition of this work.

I am deeply grateful to all the interview participants who contributed their time and insights to this study. Their openness and willingness to reflect critically on robotic-assisted surgery enriched this research far beyond what I could have achieved on my own.

To my family, especially my grandparents, I offer my heartfelt thanks. Your unconditional support and the stability you provide have been essential to my ability to pursue this degree. Your belief in me has carried me through every challenge along the way.

I would also like to thank my friends and colleagues for their encouragement, humour and companionship. Your presence made the demanding moments lighter and reminded me that progress is built not only through discipline but also through balance and connection.

Finally, I express my gratitude to everyone who, directly or indirectly, contributed to this dissertation. This work reflects not only academic effort but also the collective support that made it possible.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ACSS	Administração Central do Sistema de Saúde
AI	Artificial Intelligence
AI-METh / AMETH	Artificial Intelligence in Medical Ethics and Technology (processual framework referenced in the model)
APCiR	Associação Portuguesa de Cirurgia Robótica
DGS	Direção-Geral da Saúde
EC	European Commission
ELICIT	Effective Learning for Implementing Change in Teams
EPIS	Exploration, Preparation, Implementation, Sustainment
ERS	Entidade Reguladora da Saúde
EU	European Union
GDPR	General Data Protection Regulation
HTA	Health Technology Assessment
IDEAL	Idea–Development–Exploration–Assessment–Long-term Study
IHP	International Healthcare Professional
IR	Industry Representative
IT	Information Technology
KPI	Key Performance Indicator
MDR	Medical Device Regulation (EU)
MHLW	Ministry of Health, Labour and Welfare (Japan)
MIS	Minimally Invasive Surgery
NASSS	Non-adoption, Abandonment, Scale-up, Spread and Sustainability
NDB	National Database of Health Insurance Claims (Japan)
NHS	National Health Service (UK)
NICE	National Institute for Health and Care Excellence (UK)
OECD	Organisation for Economic Co-operation and Development
OR	Operating Room
PR	Portuguese Private-sector Healthcare Professional

PRR	Plano de Recuperação e Resiliência
PS	Portuguese Public-sector Healthcare Professional
RAS	Robotic-Assisted Surgery
SNS	Serviço Nacional de Saúde
SPCR	Sociedade Portuguesa de Cirurgia Robótica
SPMS	Serviços Partilhados do Ministério da Saúde
TAM	Technology Acceptance Model
TOE	Technology–Organisation–Environment Framework
UTAUT	Unified Theory of Acceptance and Use of Technology
VR	Virtual Reality
WHO	World Health Organisation

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“Our future is a race between the growing power of technology and the wisdom with which we use it.”

— Stephen Hawking

1. INTRODUCTION

Robotic-assisted surgery has become one of the most significant innovative developments in surgical practice over the past two decades. The first reported robot-assisted surgery was performed using the da Vinci Surgical System “Mona” in 1997 by Jacques Himpens in Belgium (Lane, 2018), influencing clinical practice, professional roles and organisational decision-making. Its global expansion across multiple specialities has been driven by expectations of improved ergonomics, enhanced precision and greater surgical capability (Marcus et al., 2024). Evidence on comparative outcomes and cost-effectiveness, however, remains mixed, and health systems continue to debate how to integrate robotic platforms safely and sustainably (Lai et al., 2024).

Across Europe, adoption has progressed unevenly due to differences in financing, workforce capacity, regulation and strategic planning. Portugal reflects this broader variability: robotic systems have expanded in recent years following a prolonged period of limited diffusion, often without a coordinated national strategy, resulting in inconsistencies in training access, procurement approaches and institutional readiness. Despite the growing presence of robotic surgery, little research has examined how stakeholders perceive its value, risks and long-term implications for clinical practice and health-system organisation. Similar gaps have been identified in international research, where the organisational, governance and sociotechnical implications of robotic-assisted surgery remain comparatively underexplored beyond clinical effectiveness assessments.

Existing literature has largely focused on technological performance or clinical outcomes, while the sociotechnical and organisational dimensions of the adoption remain less developed. Frameworks such as UTAUT and sociotechnical systems theory illustrate how individual, organisational, and contextual factors interact to shape technology uptake (Greenhalgh & Papoutsi, 2018). Portugal offers a relevant case for exploring these interactions, given its unstructured adoption trajectory and the absence of national guidance on training, governance or evaluation.

This dissertation addresses these gaps by analysing how clinicians, managers, industry representatives and international experts understand the current and future role of robotic-assisted surgery in Portugal. Using a multilevel sociotechnical lens, the study examines how perceptions, organisational conditions, and systemic dynamics influence adoption, and develops a conceptual framework connecting micro, meso, and macro determinants to support strategic planning and policy development.

The study is guided by the following research questions:

RQ1

How do stakeholders perceive the current landscape and future trajectory of robotic-assisted surgery in Portugal?

RQ2

What organisational and systemic factors influence the sustainable adoption of robotic-assisted surgery in Portugal?

RQ3

What strategies could support a more equitable, safe and ethically grounded expansion of robotic surgery in Portugal?

2. BACKGROUND

Robotic-assisted surgery (RAS) has become a central example of digital transformation in healthcare. Its adoption extends far beyond the technical performance of robotic platforms, since meaningful implementation depends on the alignment between clinical evidence, organisational culture, workflow integration, training capacity, governance mechanisms, ethical safeguards and broader regulatory structures (Greenhalgh & Papoutsi, 2018; Burke et al., 2025). This chapter establishes the conceptual foundations for understanding the complexity of RAS adoption.

The term "robot" was first introduced by Josef Čapek in 1921, deriving from the Czech word *robota*, meaning labour or work (Morrell et al., 2021). This origin is conceptually relevant, as robotic technologies were initially conceived to support and reorganise human labour rather than replace professional judgement, a perspective that remains central to sociotechnical interpretations of technology in healthcare (Floridi, 2018).

2.1 Digital Health and Innovation in Healthcare

Digital health encompasses a wide range of technologies, including electronic health records, telemedicine, AI-enabled systems and robotic platforms. Organisations such as the WHO and the OECD emphasise that digital transformation depends not only on technological sophistication but also on effective governance, committed leadership, workforce readiness and supportive organisational cultures. As several authors note, these dimensions determine whether innovations become embedded in routine practice or remain isolated pilot initiatives with limited impact.

Multiple theoretical perspectives help explain how health technologies are adopted. Rogers' Diffusion of Innovations highlights perceived advantage, compatibility, complexity, trialability and observability as key determinants of uptake (Rogers, 2003). Building on this, models such as the Technology Acceptance Model proposed by Davis (1989) and the Unified Theory of Acceptance and Use of Technology developed by Venkatesh et al. (2003) emphasise perceived usefulness, ease of use, social influence and facilitating conditions. Recent contributions in health settings further stress the role of perceived risk and trust in shaping clinicians' acceptance of digital tools, as discussed by Rahimi et al. (2018) and Heinsch et al. (2021). Although much of the empirical literature on digital health governance derives from telehealth and virtual care, these frameworks offer transferable insights into organisational readiness, governance and quality assurance relevant to other advanced medical technologies, including robotic surgery.

Yet, individual-level models alone cannot explain the adoption of complex technologies such as RAS (Scarbrough & Kyratsis, 2022). Organisational perspectives, including the Technology–Organisation–Environment framework (Tornatzky & Fleischer, 1990; Beier & Früh, 2020), underscore the importance of leadership engagement, resource allocation, and regulatory pressures in determining innovation readiness. Complementing this, sociotechnical approaches argue that adoption emerges from the interaction between technological characteristics, professional practices, institutional routines and broader system structures (Cabitza et al., 2017). These perspectives are particularly relevant for RAS, as robotic systems reshape team dynamics, workflow patterns and organisational priorities in ways that extend beyond traditional acceptance models.

Collectively, these perspectives highlight the need for multilevel approaches when analysing complex health technologies such as robotic-assisted surgery.

2.2 Evolution and Clinical Dimensions of Robotic-Assisted Surgery

RAS has expanded globally over the past two decades, with the da Vinci system achieving global prominence and newer platforms such as Versius, Hugo RAS and Hinotori widening the competitive landscape (Autorino et al., 2014). Robotic systems offer enhanced dexterity, tremor reduction, three-dimensional visualisation and improved ergonomics, features that can reduce surgeons' physical strain and support technical precision.

Clinical evidence, nevertheless, remains mixed. While several studies report reduced blood loss, shorter hospital stays and lower postoperative pain for selected procedures, others indicate comparable outcomes between RAS and advanced laparoscopy (Trastulli et al., 2015; Zou et al., 2025). As authors such as Hashimoto (2013) and Hirri et al. (2024) note, this variability underscores the importance of procedure-specific evaluation and cautious interpretation. Long-term outcomes depend on surgeon expertise, workflow standardisation and careful patient selection.

Learning curves remain central to debates on clinical performance. Effective robotic programmes require structured training, simulation-based learning, multidisciplinary coordination and sustained mentorship to ensure safety and efficiency (Sridhar et al., 2017;

Aggarwal et al., 2022). Studies consistently show that inadequate training environments and poorly organised operating-room workflows contribute to longer operative times, inconsistent outcomes and reduced cost-effectiveness (Higgins et al., 2017).

Economic considerations are equally significant. Robotic systems involve high capital investment and substantial recurring costs for maintenance, instruments and consumables. Financial sustainability largely depends on procedure volume, operating-room efficiency and coordinated scheduling, as noted by Barbash et al. (2010) and Childers et al. (2018). Low-volume institutions face particular challenges, making long-term strategic planning essential.

These clinical, economic and organisational factors intersect with ethical and governance concerns, which shape institutional readiness, professional responsibility and the sustainability of RAS programmes.

2.3 International Patterns of Robotic-Assisted Surgery Adoption

The adoption of robotic-assisted surgery (RAS) varies substantially across high-income health systems, reflecting differences in organisational structures, investment models, reimbursement frameworks and workforce planning. Comparative analysis reveals marked variation in both the timing and intensity of adoption across regions.

The United States represents the most mature robotic surgery market worldwide, characterised by early adoption, high system density and widespread integration across academic and private hospitals. Sustained investment over more than two decades and close alignment between manufacturers and clinical training pathways have supported the normalisation of robotic-assisted procedures across multiple surgical domains (Oliver Wyman, 2023; Lai et al., 2024).

Japan has followed a distinct but comparably early trajectory. Robotic surgery has been progressively incorporated into national reimbursement schemes, enabling institutional uptake across several regions. However, the adoption remains uneven, with higher procedural volumes concentrated in urban centres and academic hospitals (Hara et al., 2024; MHLW, 2022).

Across the European Union, adoption patterns are more heterogeneous. Health systems characterised by coordinated national strategies, centralised procurement mechanisms, structured training networks and national registries, such as the Netherlands and several Scandinavian countries, tend to achieve more consistent and equitable integration of robotic surgery. In contrast, other European systems exhibit fragmented diffusion driven primarily by institution-level decisions rather than national planning (WHO Europe, 2023; ERSC, 2024).

Portugal presents a distinct and compressed adoption trajectory. Robotic-assisted surgery was introduced relatively late, with the first clinical use reported around 2010, led by urologist Kris Maes within a private hospital setting (Hospital da Luz, 2010). For much of the subsequent decade, diffusion remained limited and highly concentrated, with minimal penetration in the public sector. More recently, adoption has accelerated sharply following exceptional, time-bound investment associated with national and European recovery funding (Carrola Gomes et al., 2024). While this expansion has increased system availability and procedural volume, it has occurred with limited evidence of gradual system-wide planning.

Despite recent growth, comprehensive national-level data on utilisation rates, clinical outcomes and cost-effectiveness remain limited in Portugal. Available information is largely institution-specific or derived from industry and media sources, constraining systematic benchmarking and longitudinal evaluation. Portugal combines late entry, low historical robotic density and rapid, investment-driven expansion. This compressed trajectory has intensified pressures on governance arrangements, training capacity and organisational readiness within the Portuguese health system, as reflected in recent initiatives (Gonçalves et al., 2023).

To contextualise international patterns of robotic-assisted surgery adoption**, Table 1** summarises estimated system density and adoption profiles across selected health systems representing different governance and diffusion models.

Region / Country	**Estimated[1] number of surgical robots**	**Robots per million inhabitants**	**Adoption profile**	**Basis of estimate**
United States (USA)	~5.500 – 6.200	16 – 18	Early adopter; market-driven diffusion; high volumes	Manufacturer and market reports
Japan (JPN)	~1.500 – 1.800	12 – 14	Early adoption; reimbursement-led expansion	National reimbursement and registry data
United Kingdom (GBR)	~ 600 – 700	~ 9 – 10	Centrally governed adoption; HTA-led diffusion within NHS	NHS England; NICE; national audits
Sweden (SWE)	~120 – 150	11 – 14	Coordinated planning; centralisation; public system	National and regional health authority data

[1] Estimates are derived from triangulation of publicly available sources, including manufacturer disclosures (e.g. Intuitive Surgical), national reimbursement and registry data (e.g. MHLW; NDB), and policy, audit and planning documents from national and regional health authorities (e.g. NHS England; NICE; Socialstyrelsen). Peer-reviewed studies informing adoption profiles include Barbash and Glied (2010), Øvretveit et al. (2022) and Hara et al. (2024). Figures are indicative and intended for comparative contextualisation rather than precise enumeration.

Netherlands (NLD)	~120 – 140	7 – 8	Coordinated national strategy; volume thresholds	National health system evaluations
Portugal (PRT)	~15 – 18	1.5 – 1.8	Late entry; low historical density; rapid, investment-driven expansion	National and institutional reporting

Table 1: Estimated Adoption of Robotic-Assisted Surgery Across Selected Health Systems

Taken together, **Table 1** and **Figure 1** highlight pronounced disparities in robotic surgery adoption across countries, distinguishing early adopters with sustained diffusion from health systems characterised by late and compressed adoption trajectories. Portugal emerges as a clear outlier, combining low per-capita density with a recent, investment-driven expansion.

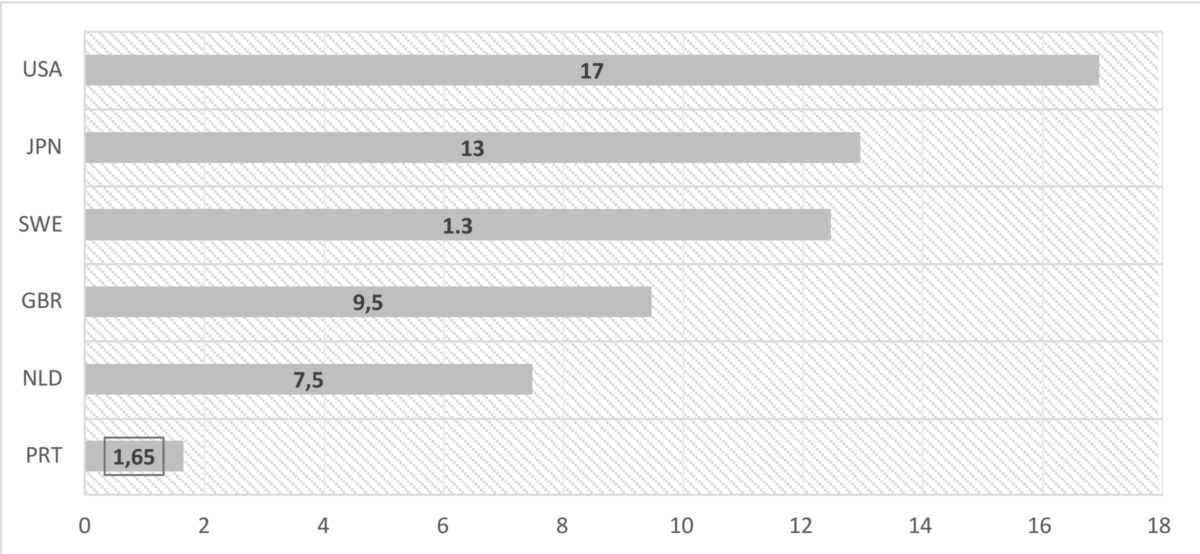

Figure 1: Density of Surgical Robotic Systems per Million Inhabitants (2025)

2.4 Ethical, Legal and Governance Considerations

RAS raises important ethical questions concerning responsibility, transparency, informed consent, data protection, patient understanding of automation and equitable access to advanced technologies. Scholars such as Dzindolet et al. (2003) highlight concerns about automation bias and the risk that clinicians may place excessive trust in machine guidance. Haltaufderheide et al. (2025) similarly note the possibility of misalignment between algorithmic outputs and clinical judgment. As AI-enabled features become more integrated into robotic systems, issues related to algorithmic bias, data provenance, explainability, system auditability and patient understanding of automated decision-support become increasingly relevant (Floridi, 2018; Brar et al., 2024), reflected in recent OECD guidance on digital health governance (OECD, 2024).

Governance frameworks in Europe are evolving to respond to these challenges. The European Union’s regulatory agenda, which includes the Artificial Intelligence Act and the Health Technology Assessment Regulation, establishes requirements for transparency, safety, oversight and lifecycle evaluation of high-risk medical technologies (European Commission, 2021). Professional bodies such as the Royal College of Surgeons set out expectations for training, accreditation, multidisciplinary preparedness and reporting structures to ensure accountable robotic-surgery programmes (RCS England, 2023; Power, 2024). Ethical governance scholarship, including work by Van Wynsberghe (2021) and Holmes et al. (2023), further argues that robotic systems redistribute agency and require governance models that address shared responsibility and relational dynamics within clinical teams.

2.5 Organisational Adoption and Sociotechnical Complexity

Implementing RAS requires substantial structural, cultural and operational adjustments. Classical change-management theories emphasise leadership, shared purpose and staff engagement, with Kotter’s framework illustrating the importance of vision, communication and empowerment in organisational transformation (Kotter, 1996). In parallel, structured models such as the IDEAL framework offer staged guidance for evaluating surgical innovations from early development to long-term monitoring (McCulloch et al., 2009).

However, these approaches alone do not capture the complexity of introducing a technology that simultaneously reshapes clinical roles, resource allocation, workflow coordination, operating-room configuration and institutional priorities. Empirical studies show that successful robotic programmes depend on collective leadership, psychological safety and effective multidisciplinary communication, as highlighted by Edmondson (1999). Organisational readiness is shaped not only by financial and technical capacity but also by digital maturity, openness to change and the ability to integrate new routines into existing service structures (Hull et al., 2012).

Sociotechnical perspectives, therefore, provide a more comprehensive lens. The NASSS framework **(Figure 2)** conceptualises adoption across interacting domains, including the clinical condition, the technology, the value proposition, user perspectives, organisational capacity, system influences and long-term sustainability (Greenhalgh et al., 2017). This emphasis on evolving complexity is particularly relevant to RAS, where institutional trajectories vary considerably.

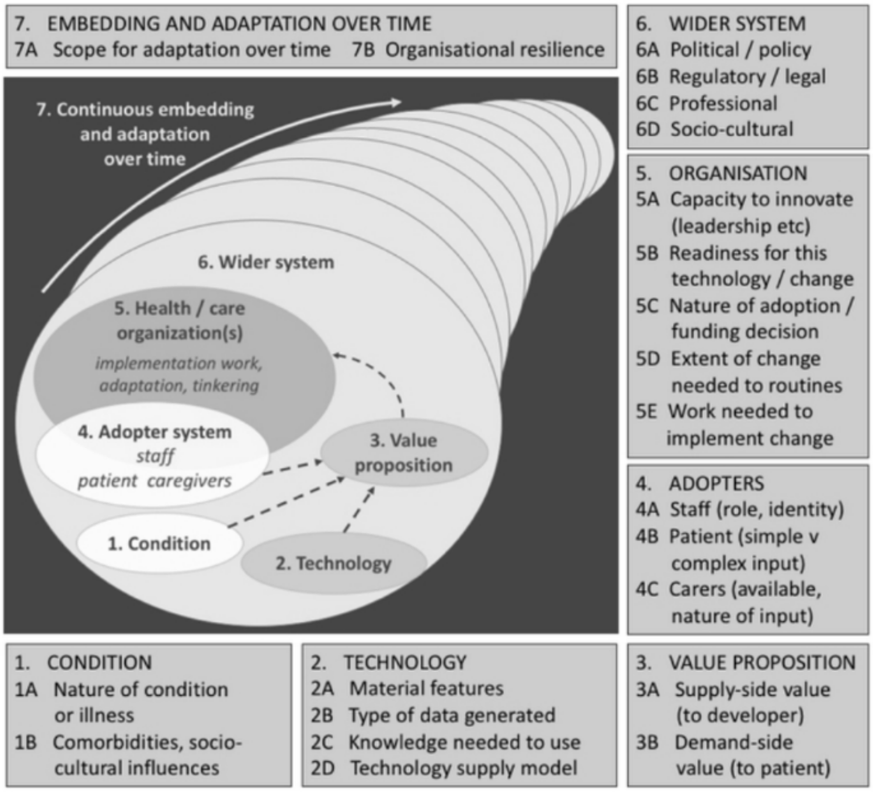

Figure 2: The NASSS Framework

Comparative analyses show that while each theoretical model provides valuable insights, none captures the full range of clinical, organisational, and systemic determinants shaping RAS adoption. **Table 2** summarises the main strengths and limitations of these frameworks.

Model	**Primary Focus**	**Key Strength**	**Limitation for RAS**
UTAUT	Individual acceptance	Explains behavioural intention and clinician perceptions	Does not consider organisational or policy level factors
TOE	Organisational readiness	Highlights leadership, resources and external environment	Limited consideration of clinical and workflow complexity
NASSS	Sociotechnical complexity	Provides a comprehensive multilevel perspective	Requires careful contextual adaptation to each implementation setting
IDEAL	Surgical innovation lifecycle	Offers structured guidance on evaluating surgical techniques	Does not integrate system level or organisational determinants
Ethical frameworks	Autonomy, fairness, accountability	Identify ethical risks and governance needs	Limited operational detail for complex clinical technologies

Table 2: Comparative Overview of Theoretical Models Relevant to RAS

2.6 Synthesis and Conceptual Foundations for Proposed Model

The literature shows that RAS adoption is shaped by interconnected factors operating at micro, meso and macro levels. Micro-level determinants include surgeon competence, learning curves, confidence and perceptions of usefulness and risk, as described in classic technology acceptance research (Davis, 1989; Venkatesh et al., 2003). At the meso level, organisational readiness, workflow integration, leadership, governance structures, training capacity and financial planning are central influences, as highlighted by Kotter (1996) and Appelbaum et al. (2012). Macro-level determinants relate to national regulatory frameworks, financing mechanisms, procurement strategies and broader digital maturity across the health system (European Commission, 2021; WHO, 2024).

Sociotechnical perspectives emphasise that these factors interact dynamically across time and institutional contexts. Work by Greenhalgh et al. (2017) illustrates how technology adoption reflects reciprocal interactions between human practices, organisational arrangements and system-level forces. Ethical and governance considerations further shape how robotic technologies are perceived, integrated and sustained, particularly as AI-enabled features transform expectations around transparency, agency and responsibility (Moor, 2006; Van Wynsberghe, 2021).

Beyond theoretical models, empirical studies across different health systems provide insights into how robotic-assisted surgery has been adopted, governed and integrated into practice. International research highlights recurring challenges related to training structures, organisational readiness, governance arrangements and alignment between investment decisions and clinical capacity, albeit shaped by distinct institutional contexts. Against this backdrop, **Table 3** synthesises selected international studies from diverse health systems, including market-led, publicly governed and hybrid models, to position the Portuguese case within the wider evidence base. These comparative insights inform and reinforce the need for a multilevel analytical framework tailored to the Portuguese context. While early studies established foundational insights into the diffusion of robotic surgery, more recent research has shifted attention towards governance, organisational readiness and system-level coordination, reflecting the maturation and scale-up of robotic technologies across health systems.

Study	Country/System	Focus	Key Insights
Barbash & Glied (2010); Childers et al. (2022); Marcus et al. (2024)	USA	Diffusion & costs	Market-driven adoption; persistent governance gaps

Hashimoto (2013); MHLW (2022); Hara et al. (2024)	Japan	Regulation & reimbursement	Adoption accelerates after national approval and credentialing
Greenhalgh et al. (2017); Aggarwal et al. (2022); RCS England (2023)	UK (NHS)	Organisational adoption	Leadership and system governance shape uptake
Iversen & Anell (2016); Øvretveit et al. (2022)	Sweden	System readiness	Centralisation supports safety and sustainability
Floridi (2018); WHO Europe (2023); ERSC (2024)	EU (multi-country)	Governance & training	Coordination and accreditation critical for equitable adoption

Table 3: Selected International Studies on Robotic Surgery Adoption and Governance

No existing framework fully captures the complexity of RAS adoption, especially in Portugal, where decentralised decision-making and heterogeneous institutional capacities create divergent implementation pathways. This dissertation therefore proposes a context-specific conceptual model that integrates clinical, organisational, ethical and policy dimensions. This need is especially visible in the Portuguese context, where prior analyses have not yet combined clinical, organisational and system-level determinants into a unified structure capable of guiding sustainable adoption. **Figure 3** introduces the triangulation structure linking governance and leadership, innovation adoption and trustworthy AI, which provides the overarching conceptual foundation for the proposed model. **Figure 4** then presents the micro-, meso- and macro-level analytical framework that operationalises this logic and structures the subsequent empirical analysis.

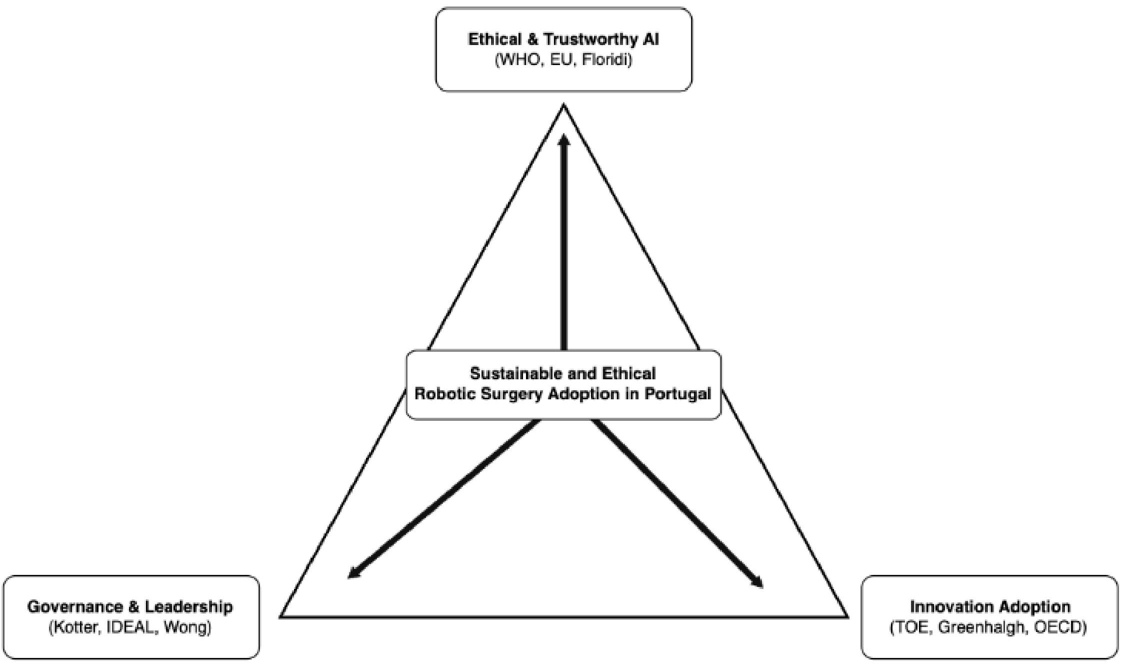

Figure 3: Triangular Framework for Sustainable and Ethical Robotic Surgery Implementation in Portugal

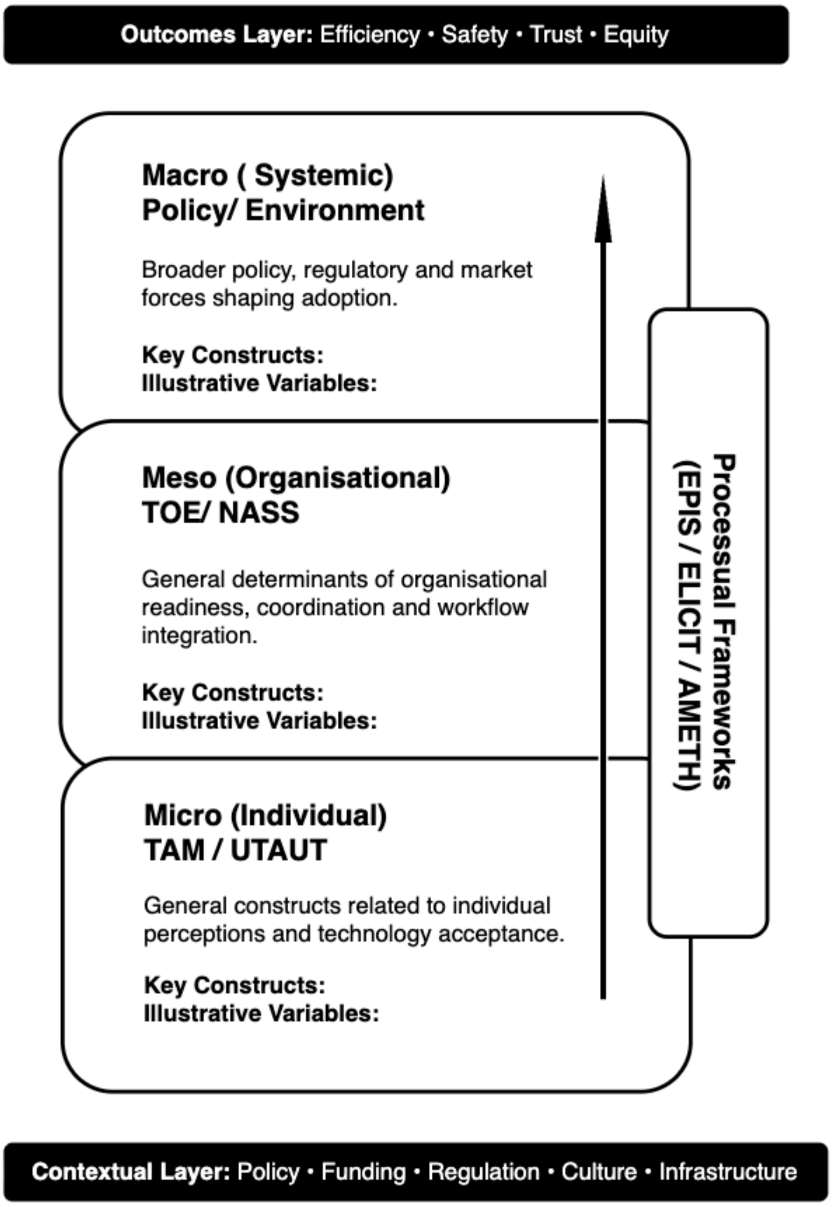

Figure 4: Preliminary Multilevel Conceptual Framework for RAS Adoption

3. RESEARCH METHODOLOGY

Departing from the identified problem and research questions (see Introduction) and using the conceptual framework presented in Background, a multistage methodology was adopted (**Figure 5**), which illustrates the overall methodological flow guiding the study from the problem statement to theme development.

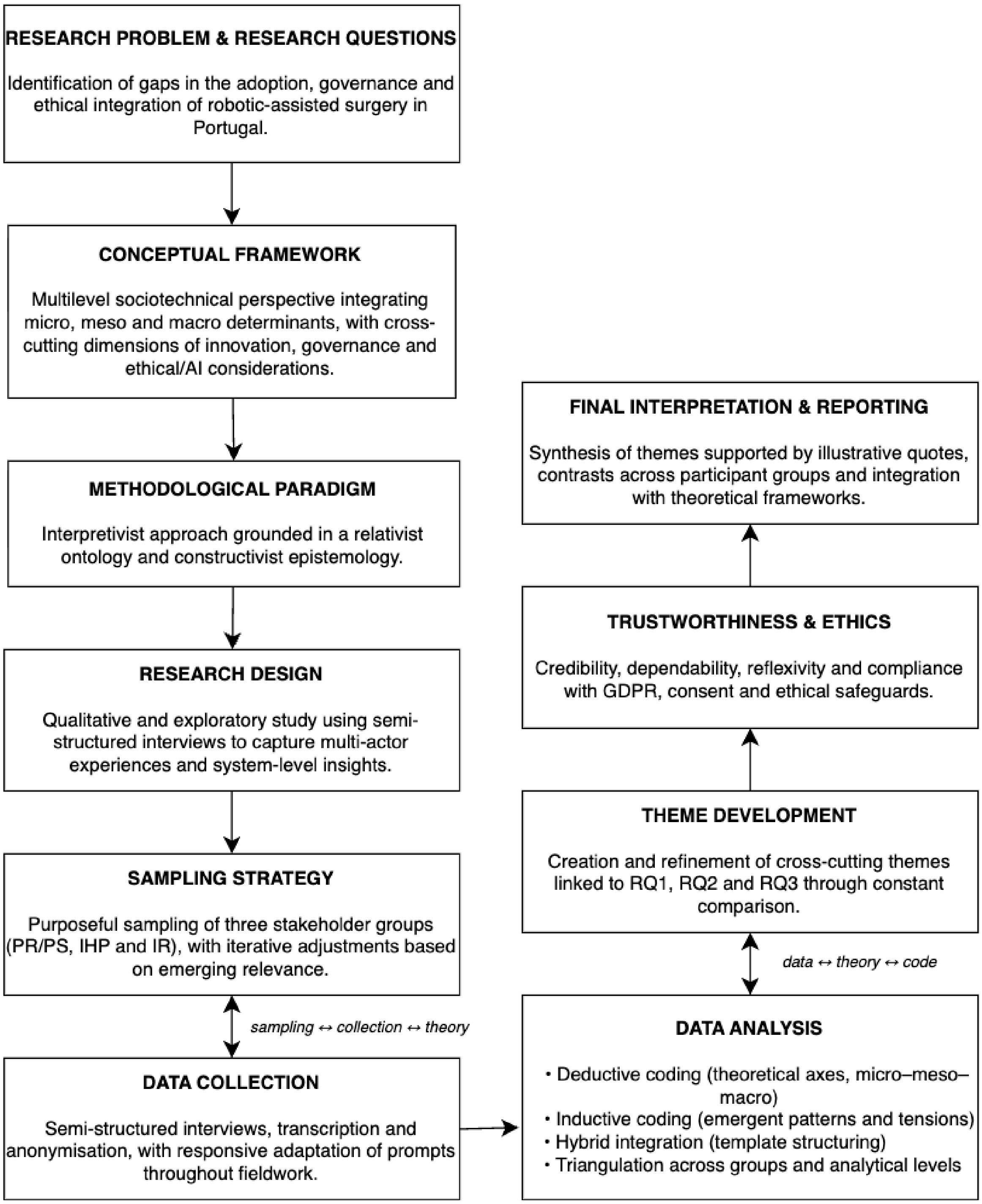

Figure 5: Conceptual Overview of the Methodological Approach

3.1 Research Design

This dissertation adopts a qualitative, exploratory and interpretivist research design to examine how robotic-assisted surgery is implemented, governed and experienced within Portuguese hospitals. **Figure 6** illustrates the research process, from problem formulation to the development of analytical themes.

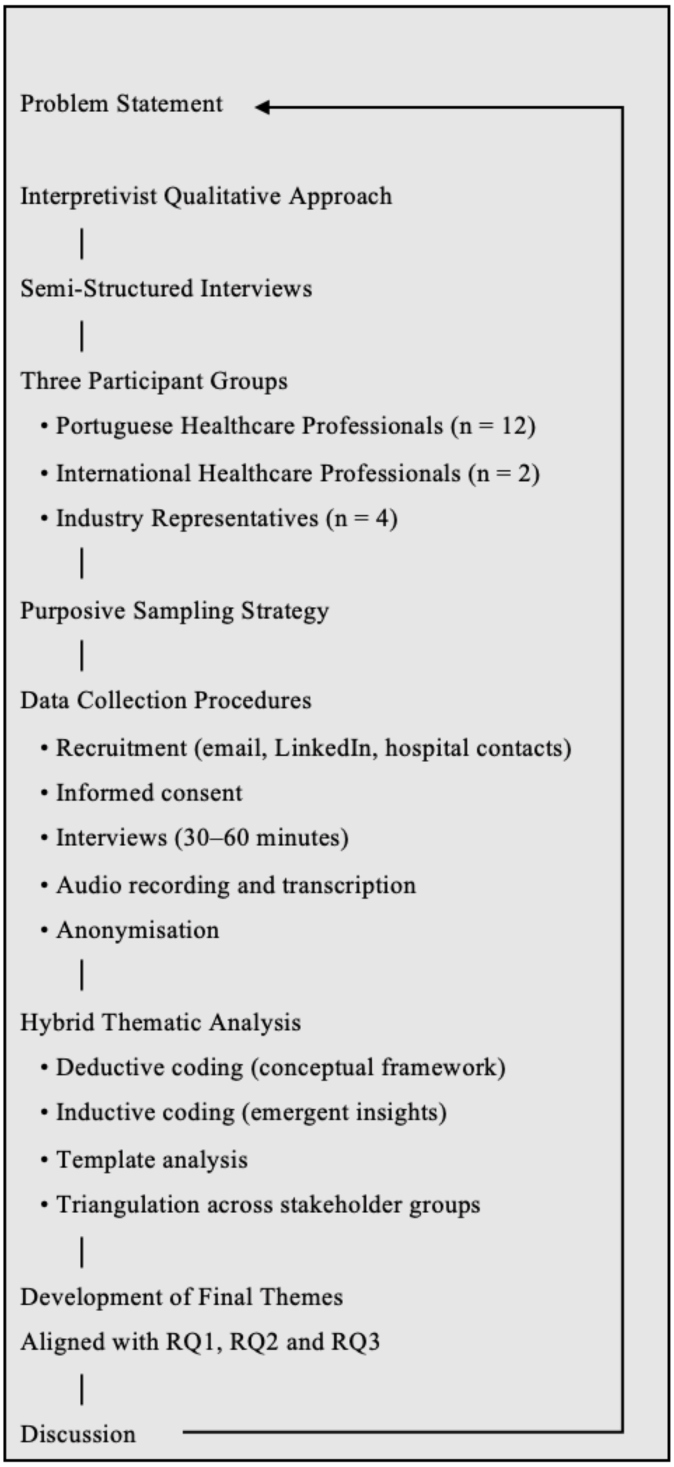

Figure 6: Overview of the Research Design

3.1.1 Philosophical Underpinnings (Ontology, Epistemology and Methodological Stance)

The study is grounded in a relativist ontology, which assumes that multiple realities coexist and are shaped by the interpretations and experiences of actors involved in robotic-assisted surgery, as originally conceptualised by Lincoln and Guba (1985). Within an interpretivist epistemology, robotic surgery is understood as a sociotechnical innovation shaped by clinical practices, organisational structures, financing models, national policy and evolving technological capabilities. This perspective emphasises meaning-making, professional identity and local institutional contexts in shaping technology integration. Semi-structured interviews were therefore selected as the primary data-collection method, allowing participants to articulate nuanced experiences while maintaining comparability across interviews, consistent with interpretivist methodological traditions (Kvale & Brinkmann, 2015; Creswell & Poth, 2018).

3.1.2 Justification for a Qualitative Approach

A qualitative approach was selected, as the research questions focus on the processes, perceptions and contextual factors influencing robotic-surgery adoption at institutional, organisational and systemic levels. These dynamics require interpretative depth and contextual sensitivity that quantitative approaches cannot provide. Semi-structured interviews enable clinicians, managers and industry representatives to reflect on constraints, decision-making processes and perceived value and risks. As argued by Eisenhardt (1989) and Greenhalgh et al. (2017), this method supports triangulation across perspectives and the identification of broader patterns, aligning with methodological guidance for studying complex healthcare innovations.

3.2 Data Collection

3.2.1 Sampling Strategy and Participant Selection

In line with the qualitative orientation of the study, purposive sampling was used to identify participants with direct experience in robotic-assisted surgery. This approach supports qualitative studies prioritising depth and expertise over statistical representativeness (Patton, 2015; Miles et al., 2014). Eligible participants held clinical, managerial, operational or strategic roles related to robotic systems.

The final sample comprised 18 participants: 12 Portuguese clinicians across specialities and sectors, 2 international clinicians from established robotic ecosystems and 4 industry representatives from global manufacturers. Recruitment occurred through LinkedIn, professional networks, hospital contacts and email outreach. The specialised nature of the field is reflected in response rates: 78 Portuguese clinicians contacted yielded 12 interviews; 42 international clinicians yielded 2; 37 industry professionals yielded 4. Interviews continued until thematic saturation was reached, consistent with the approach of Guest et al. (2006).

Recruitment flows and participation outcomes are summarised in **Table 4**. Additional anonymised contextual details for each participant are provided in **Appendix 3.**

	Invited	Result			
		Not Interested[2]	Interested	Accepted	**Participants**
Portuguese Healthcare Professional ***(PR/PS)***	78	55	23	20	**12**
International Healthcare Professional ***(IHP)***	42	32	10	6	**2**
Industry Representative ***(IR)***	37	31	6	5	**4**
Total	*157*	*118*	*39*	*31*	***18***

Table 4: Recruitment Flow and Participation Outcomes Across Participant Groups

3.2.2 Development of the Interview Guides

The interview guides were developed iteratively, informed by literature on innovation adoption, organisational readiness, surgical innovation, governance and responsible AI. An initial 22 question guide was piloted with a professional working in robotic surgery eligible for participation, revealing redundancies and potential respondent fatigue. Following recommended procedures for qualitative instrument refinement (Kvale & Brinkmann, 2015; Castillo-Montoya, 2016), the guide was streamlined into 12 essential questions and adapted into three versions tailored to Portuguese clinicians, international clinicians, and industry representatives. **Appendix 1** includes all versions of the interview guides.

[2] Includes recipients who did not reply and those who forwarded the invitation to further individuals without interest in the study themselves.

3.2.3 Data Collection Procedures

Data collection occurred between October and December 2025 through in-person and online interviews conducted via Microsoft Teams, in Portuguese or English. Interviews began with an explanation of the study's aims, confidentiality and data-protection procedures, followed by informed consent. Each interview lasted 30–60 minutes. Participants discussed organisational decision-making, workflow integration, training requirements, procurement, financing mechanisms, governance structures, ethical considerations and national constraints. With permission, interviews were audio-recorded and transcribed or documented through analytic notes. All data were anonymised in compliance with GDPR. **Appendix 2** provides synthesised transcripts and contextual notes.

3.2.4 Ethical Considerations

Ethical procedures followed institutional and legal standards for research involving professionals. Participants were informed of the study's purpose, voluntary participation and confidentiality safeguards. No patient-level data were collected. Identifiers were removed during transcription, and data were securely stored in encrypted, access-controlled files for academic use only.

3.3 Data Analysis

Data analysis followed a hybrid thematic approach designed to capture both theoretically informed and empirically emergent insights into robotic-assisted surgery adoption. This approach reflects the study's interpretivist stance and its focus on understanding complex sociotechnical dynamics across multiple analytical levels (Creswell & Poth, 2018; Greenhalgh & Papoutsi, 2018). By integrating inductive and deductive strategies, the analysis maintains coherence with the conceptual frameworks outlined in the literature review while remaining grounded in participants' accounts. **Figure 7** provides a visual orientation to this analytical logic, situating the different stages of analysis within the overall research design.

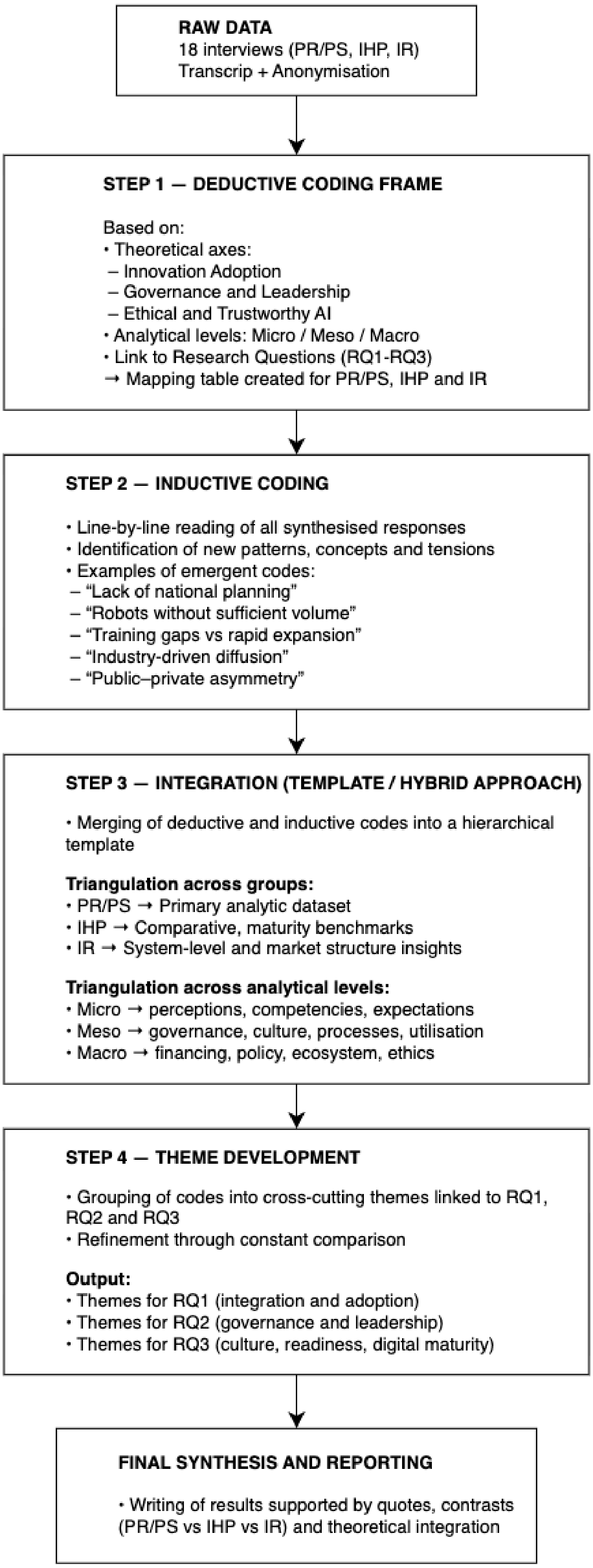

Figure 7: Hybrid Thematic Analysis Process

3.3.1 Analytical Framework (Thematic and Template Analysis)

Data analysis followed a hybrid thematic approach combining inductive and deductive strategies, consistent with reflexive thematic analysis (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006). Deductive coding drew on two conceptual frameworks introduced in the Background (**Figures 3** and **4**): an integrative framework linking innovation adoption, governance and ethical AI, and the micro–meso–macro sociotechnical model. In line with Blumer (1954) and Bowen (2006), these served as sensitising concepts guiding early coding while allowing inductive insights to emerge. The Integrative Mapping Table in **Appendix 4** links each interview question to stakeholder group, analytical level, theoretical domain and corresponding research question.

3.3.2 Coding Process (Linked to Conceptual Models)

Coding began with repeated reading of transcripts and analytic notes. Deductive codes reflected micro-level constructs (e.g., perceived usefulness, risk perception), meso-level constructs (e.g., leadership capacity, workflow integration) and macro-level constructs (e.g., national strategy, reimbursement policy, vendor ecosystems). Inductive coding generated complementary insights, including expansion of robotic systems in low-volume centres, misalignments between investment decisions and clinical capacity, training bottlenecks and differences in readiness between public and private institutions.

Template analysis consolidated deductive and inductive codes into broader themes. **Figure 8** illustrates how themes distributed across analytical levels differentiate determinants of adoption from stakeholder perceptions. Triangulation across groups strengthened interpretative robustness and enriched understanding of interactions between clinical practice, organisational management and industry strategy.

The coding structure was iteratively refined until thematic stability was achieved across interviews.

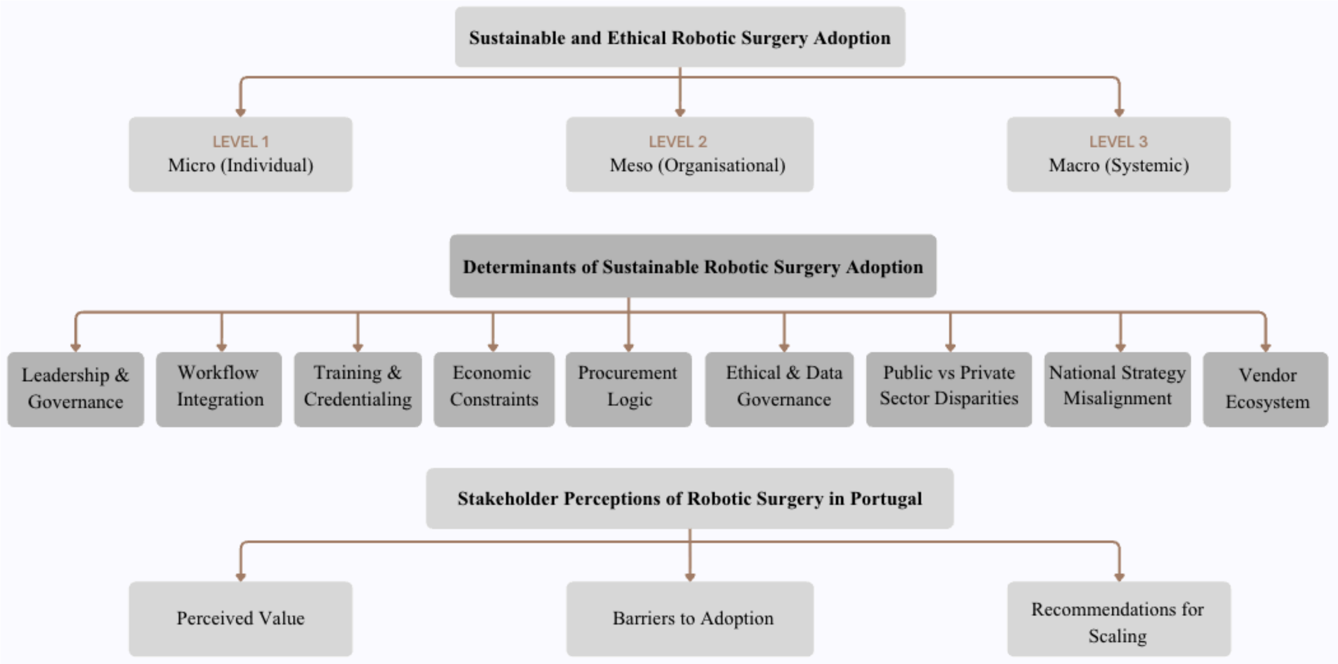

Figure 8: Analytical Framework for Multilevel Thematic Analysis

3.3.3 Ensuring Validity, Reliability and Rigour

Trustworthiness was assessed against Lincoln and Guba's (1985) criteria. Credibility was enhanced through multi-stakeholder triangulation and iterative engagement. Transferability was supported by detailed contextual descriptions of participants and settings. Dependability was reinforced by documenting analytical procedures and coding decisions. Confirmability was achieved through anonymisation, reflexive documentation of the researcher´s positionality, and grounding interpretations in empirical evidence. Reflexive notes were maintained throughout the research process to support transparency and analytical integrity. **Appendix 2** supports confirmability, and **Appendix 4** reinforces dependability by outlining the analytical pathway.

3.4 Limitations of the Methodological Approach

Several limitations should be considered when interpreting the findings of this study. First, the use of purposive sampling limits statistical generalisability, as the findings may not capture the full range of institutions, professional roles or organisational settings involved in robotic surgery in Portugal. Access to industry representatives was constrained by corporate communication policies, which reduced the diversity of industry perspectives included. In addition, the participation of only two international clinicians limits the depth of direct cross-country comparison.

The findings also reflect a specific moment in the Portuguese adoption trajectory, characterised by rapid expansion following a prolonged period of limited diffusion. As such, stakeholder perceptions captured in this study may evolve as organisational routines, training structures and governance mechanisms mature over time. Furthermore, the absence of comprehensive national quantitative data on utilisation, outcomes and costs restricts the ability to triangulate qualitative insights with system-level performance indicators.

As with all qualitative research, the analysis is shaped by interpretive judgement. Reflexivity was therefore maintained throughout the research process, with analytic decisions continuously examined in relation to the researcher's assumptions, positionality and engagement with the data. Despite these limitations, the triangulated stakeholder design, multilevel conceptual framing and systematic analytical approach enhance methodological rigour. The study prioritises analytical transferability over statistical representativeness, and the detailed contextualisation provided supports its relevance to comparable health-system settings.

4. RESULTS

4.1 Participant Overview

Eighteen participants contributed to this study, offering a multi-layered perspective on robotic-assisted surgery (RAS) in Portugal. The core analytical dataset comprises twelve Portuguese healthcare professionals across private (PR1–PR6) and public hospitals (PS1–PS6), representing urology, general surgery, hepatobiliary, metabolic, colorectal, thoracic and orthopaedic specialities, as well as perioperative nursing. These participants form the primary empirical basis for addressing the research questions.

To contextualise the Portuguese experience, the study also incorporates insights from two international clinicians (IHP1–IHP2) working in high-volume Scandinavian robotic centres and four industry representatives (IR1–IR4) from major global manufacturers. These complementary perspectives provide comparative and system-level insights into governance, technology diffusion and market dynamics.

Given that robotic surgery adoption is shaped by interactions between individual perceptions, organisational capacity and wider policy and market forces, the findings are structured according to the micro–meso–macro analytical framework presented in the conceptual model. This structure ensures coherence with the literature review and supports a systematic, multi-level interpretation of the results.

4.2 Thematic Findings (Micro–Meso–Macro)

4.2.1 Micro-Level Factors (Individual Perceptions, Attitudes and Experiences)

Micro-level findings capture how individual clinicians and perioperative staff perceive, learn and integrate robotic-assisted surgery (RAS) into their professional practice. Across interviews, participants described RAS as a meaningful technological evolution offering clinical, ergonomic and motivational advantages, although experiences varied according to training opportunities, exposure and institutional maturity.

A consistent theme was the perception of clear clinical value. Surgeons emphasised improvements in precision, articulation and visualisation, particularly for anatomically complex procedures such as prostatectomies or hepatobiliary resections. These perceived benefits acted as strong motivators for adoption. As one urologist noted, *"Robotics gives us a level of precision we simply cannot achieve in laparoscopy; for prostate cancer this makes a real difference"* (PR1). Several participants also highlighted improved ergonomics and reduced physical strain, linking robotic surgery to long-term career sustainability and professional identity.

Skill acquisition and confidence were closely associated with structured training and procedural volume. While many clinicians found the robotic interface intuitive after initial training, several stressed that competence deteriorates rapidly without regular practice. As one participant stated, *"You cannot become safe by doing one or two cases a month; skills decay quickly"* (PS5). Perioperative nurses echoed this concern, describing early uncertainty regarding docking, troubleshooting, and emergency procedures, which reinforced the importance of team-based training rather than surgeon-centred approaches alone.

Perceptions of risk and trust were generally favourable. Participants consistently stressed that current robotic platforms remain fully surgeon-controlled, countering common assumptions about automation. Concerns instead focused on human factors, particularly premature autonomy or insufficient preparation. As one industry representative explained, *"The robot is safe; what worries me is people thinking they are ready before they are"* (IR2). Risk was therefore framed not as an inherent property of the technology but as a consequence of inadequate training, inconsistent utilisation or limited organisational support.

Finally, robotic surgery emerged as an important source of professional motivation, particularly among younger surgeons who viewed RAS proficiency as essential for career progression and institutional competitiveness. Professionals working in high-volume centres reported stronger engagement and clearer development trajectories, while those with irregular access to the robot expressed frustration and concerns about skill stagnation. As one participant noted, *"If we want to stay competitive and attract new surgeons, robotics is essential"* (PS2).

Overall, micro-level findings indicate a predominantly positive orientation toward robotic surgery, shaped by perceived clinical value, motivation and trust in the technology. However, these perceptions are strongly moderated by training continuity, exposure and organisational context. These insights directly inform Research Question 1 and contribute to Research Question 3 by illustrating how individual experience and learning environments influence institutional readiness.

These patterns are synthesised in **Table 5**, which groups participants according to shared perceptions of value, confidence, constraints and training exposure.

Cluster	Participants	Profile	Key Characteristics	Example Quotes
High-Confidence Users	PR1, PR2, PR4, PS1, PS2, IHP1	Experienced users	High perceived clinical value; strong motivation; routine integration of RAS	"For us, the robot is already the standard approach for complex cases." (PS2)
Cautiously Positive Users	PR3, PR5, PS3, PS4, PS5, IHP2	Enthusiastic but constrained	Value RAS but emphasise volume, mentoring and organisational readiness	"I see clear benefits, but without proper mentoring the risks increase." (PR5)
Under-Supported Users	PR6, PS6, IR2	Institutionally constrained	Limited training and access; concerns about readiness and responsibility	"Access is limited, and that creates pressure to learn too fast." (PR6)

Table 5: Participant Clusters at the Micro Level

4.2.2 Meso-Level Factors (Organisational Governance, Resources, and Workflow Integration)

Meso-level findings reveal substantial variation in how Portuguese hospitals organise, govern and operationalise robotic-assisted surgery (RAS). Unlike the micro level, where participants expressed broadly similar attitudes regarding clinical value and motivation, organisational differences emerged as one of the strongest determinants of adoption, continuity and programme maturity. These differences were particularly evident when comparing public and private institutions, and hospitals at different stages of implementation.

Participants working in well-established robotic programmes described structured coordination, predictable scheduling and strong institutional backing. These hospitals, found predominantly in the private sector and in a small number of high-volume public centres, had formal or semi-formal governance arrangements that clarified training pathways, credentialing processes, workflow integration and strategic objectives. Clinicians in these settings reported regular access to the robot, stable case volumes and the presence of designated clinical leadership, conditions that supported team cohesion and continuous skill development. As one surgeon explained, *"We have fixed weekly schedules by speciality; utilisation is around 90 to 95% annually"* (PR1).

In contrast, participants from intermediate-stage programmes, particularly in the public sector, described significant operational constraints that limited full integration. Common challenges included restricted operating theatre availability, competition for operating room time across specialities and shortages of anaesthesiology staff. Several clinicians noted that robotic sessions were negotiated on an ad hoc basis, creating unpredictability and contributing to skill stagnation. As one surgeon stated, *"We would use the robot more, but we simply do not have OR time; anaesthesiology is the bottleneck"* (PS3). Training opportunities at these institutions were also inconsistent, with programme expansion constrained by workforce shortages and bureaucratic approval processes rather than by a lack of clinical interest.

A smaller group of participants described institutions in nascent or under-resourced programmes, where robotic systems had been acquired before adequate organisational conditions were in place. In these settings, participants reported limited access to the robot, absence of formal governance structures and poorly defined training pathways. Several expressed frustration that acquisition had preceded strategic planning, resulting in underutilisation and slow progression along the learning curve. As one clinician noted, *"The robot was purchased before a team existed; now we are trying to build the programme from scratch"* (PS6).

Clear contrasts emerged between public and private institutions. Private hospitals were consistently described as more agile in decision-making, with faster procurement processes, greater financial autonomy, and stronger internal capacity to fund training. These institutions often embed robotic surgery within broader organisational strategies focused on competitiveness, talent attraction and patient experience. Participants also highlighted higher levels of digital maturity in the private sector, including the use of performance dashboards, scheduling tools and monitoring indicators.

Public hospitals, by contrast, operated within more rigid administrative and financial frameworks. Many depended on external funding mechanisms for acquisition and lacked dedicated budgets for training and programme development. Several clinicians reported financing their own training abroad, and workforce shortages in anaesthesiology and perioperative nursing were repeatedly identified as limiting factors. Bureaucratic procurement processes further constrained access to consumables, simulation tools and maintenance support. Participants emphasised that while some public centres achieved high levels of maturity, others struggled to move beyond pilot-stage activity due to structural limitations rather than clinical resistance.

Several clinicians described strong motivation to develop robotic surgery as part of professional growth and institutional modernisation, while perceiving that management remained cautious due to high initial costs and delayed return on investment. As one participant noted, "*surgeons want to grow with robotic surgery, but from a management perspective the first years are seen as a cost, not as a return"* (PS5).

International clinicians reinforced these observations by noting that high-volume European centres rely on formal governance structures, multidisciplinary training pathways and alignment between clinical and administrative leadership. As one international participant noted, *"in high-performing centres, robotic surgery is treated as a programme, not as a machine"* (IHP1). Industry representatives similarly emphasised that sustained utilisation depends on institutional readiness, operational discipline and long-term planning rather than on technology acquisition alone, noting that *"buying the robot is the easy part; building the system around it is what determines success"* (IR2).

Overall, meso-level findings demonstrate that organisational conditions, particularly governance quality, workflow integration, leadership capacity and resource allocation, play a decisive role in shaping the trajectory and sustainability of robotic surgery programmes in Portugal. These findings directly address Research Question 2 and contribute to Research Question 3 by illustrating how organisational readiness mediates the translation of individual motivation into sustained clinical practice.

The contrasts between public and private institutions, particularly in scheduling, financing and digital maturity, are synthesised in **Table 6**.

Dimension	Private Hospitals (PR)	Public Hospitals (PS)	International / Industry Context
Financing & Investment	Internal funding; agile procurement	PRR-dependent[3]; slower processes	Mixed models sustain long-term growth (IHP/IR)
OR Scheduling & Utilization	Predictable, high utilization (80–95%)	Variable; often limited by staffing	High-volume centres outperform (IHP1)
Training & Credentialing	Structured, institution-funded pathways	Self-funded; inconsistent structures	Standardization essential (IHP2)
Governance & Leadership	Clear leadership; committees more frequent	Often informal or weak	Governance reduces variability (IR2)
Digital Maturity	Dashboards and data-driven monitoring	Uneven; limited indicators	Data integration key to quality (IHP1)
Cultural Readiness	Strong innovation culture; talent attraction	Mixed; affected by bureaucracy	Culture predicts sustainability

Table 6: Organisational Comparison Between Public and Private Hospitals

4.2.3 Macro-Level Factors (Policy, Funding, National Strategy and Market Dynamics)

Macro-level findings highlight how national policy, funding mechanisms, regulatory frameworks and market dynamics shape the adoption and sustainability of robotic-assisted surgery (RAS) in Portugal. Although many participants described challenges rooted in their daily clinical or organisational contexts, interview narratives converged on the view that wider

[3] PRR refers to Portugal's Recovery and Resilience Plan; PRR-dependent indicates reliance on this programme as the primary source of capital investment.

system-level conditions exert a decisive influence on institutional readiness and long-term programme viability.

A central theme concerned national funding mechanisms, particularly the Recovery and Resilience Plan (PRR). Participants widely recognised the PRR as a critical enabler of robotic acquisition in the public sector, enabling hospitals to access platforms that would otherwise be unattainable. At the same time, many expressed concern that capital investment was not matched by corresponding funding for training, staffing or long-term maintenance. As one surgeon explained, *"The PRR paid for the robot, but not for the conditions needed to use it properly"* (PS2). This mismatch often led to situations in which equipment acquisition preceded programme maturity, contributing to underutilisation and fragmented activity. Industry representatives reinforced this point, emphasising that sustainable adoption depends on lifecycle planning rather than one-off procurement.

Another recurring macro-level determinant was the absence of national coordination or strategic planning for robotic surgery. Participants described significant variation in how hospitals interpreted the role and scope of RAS, with no shared national vision regarding indications, distribution, volume thresholds or outcome monitoring. As one international clinician observed, *"In high-volume countries, centres are designated, volumes are predictable and outcomes are monitored; Portugal is still building that structure"* (IHP1). In the absence of central guidance, programme development remained heavily dependent on local champions and institutional capacity, reinforcing inequalities across hospitals.

Workforce constraints also emerged as a critical system-level barrier. National shortages of anaesthesiologists and trained perioperative nurses were repeatedly cited as limiting operating room capacity and restricting the expansion of robotic programmes. Even highly motivated institutions faced bottlenecks that reduced procedural volume and disrupted learning continuity. As one clinician noted, *"We have the robot and the demand, but not the people to run the rooms"* (PS3). These workforce dynamics not only constrained utilisation but also undermined efforts to maintain proficiency and ensure patient safety.

Market structure further influenced adoption trajectories. Participants highlighted Portugal's long-standing dependence on a single dominant vendor, which shaped pricing, training pathways and platform availability. Several noted that limited competition historically restricted access and delayed diversification. In practice, this dependence was not perceived as purely commercial but as structurally reinforced by vendor-specific training ecosystems. As one participant explained, *"Training on one robot does not automatically transfer to another, it's like switching from one car brand to another: you still drive, but everything feels different"*

(IR3). This lack of interoperability at the training and usability level increases switching costs for hospitals and reinforces path dependency. Although new robotic platforms are entering the European market, their diffusion in Portugal has been gradual. As one industry representative explained, *"The ecosystem is changing, but hospitals need governance and evaluation capacity to compare systems objectively"* (IR3). International participants echoed this view, emphasising the role of competitive procurement and structured assessment in supporting strategic alignment and cost-effectiveness.

Finally, macro-level findings underscored regulatory and data-governance gaps. Participants expressed uncertainty regarding future AI integration, data ownership and responsibility for algorithmic decision support. Several noted the absence of national registries, harmonised indicators and systematic safety auditing. As one international participant remarked, *"In Scandinavia, every robotic case feeds into a national registry; that is what allows transparency and improvement"* (IHP2). The lack of comparable mechanisms in Portugal limits oversight and constrains the capacity for system-wide evaluation and learning.

Overall, macro-level findings demonstrate that national funding structures, strategic gaps, workforce shortages, vendor market concentration and regulatory limitations collectively shape the environment in which hospitals attempt to implement robotic surgery. These systemic conditions amplify institutional disparities and determine whether RAS develops into a coordinated national capability or remains a fragmented set of local initiatives. These insights inform Research Question 1 and provide essential context for Research Question 3 by clarifying how health-system architecture enables or constrains sustainable adoption.

The principal macro-level facilitators and barriers identified across interviews are synthesised in **Table 7**.

Macro-Level Factor	Description	Impact on Hospitals	Supporting Insights
National Funding Models	PRR-driven capital investment without matched operational funding	Robots acquired but training and staffing underfunded	"Capital investment happened much faster than organisational preparation." (IR1)
Lack of National Strategy	Absence of designated centres, volume criteria, or coordinated planning	Uneven expansion; maturity depends on individual hospitals	"Each hospital is developing its own approach, without clear national coordination." (PS5)
Workforce Constraints	National shortages in anaesthesiology and perioperative nursing	Limits OR capacity, slows program growth	"We have demand and equipment, but human resources are the limiting factor." (PR6)

Market Concentration	Dominance of a single vendor; slow diversification	High dependence; limited choice; training tied to vendors	“Market dominance influenced not only prices, but also how training was organised.” (IR3)
Regulatory & Data Gaps	No unified indicators or registries	Limited monitoring and evaluation	“Hospitals collect data, but there is no shared framework for comparison.” (IHP1)

Table 7: Macro-Level Determinants of Robotic Surgery Adoption in Portugal

4.3 Cross-Level Themes and System-Level Synthesis

Across the three analytical levels, several cross-cutting themes emerged that illustrate how individual experience, organisational capacity and national context interact to shape the implementation of robotic-assisted surgery (RAS) in Portugal. These themes highlight structural tensions, enabling conditions and the mechanisms through which system-level constraints influence professional practice. The interactions across analytical levels are synthesised in **Table 8**.

Level of Analysis	Facilitators Identified	Barriers Identified	Interaction Across Levels
Micro (Individual)	High perceived clinical value; strong motivation; increased confidence with experience	Skill decay with low volume; uncertainty with limited training; reliance on informal learning	Micro-level enthusiasm depends on organisational resources and system-level workforce availability
Meso (Organisational)	Effective leadership; structured training; stable OR scheduling; consistent volume	Workforce shortages; limited anaesthesiology; irregular access to robot; bureaucratic delays	Organisational maturity amplifies or restricts micro-level skill development and macro-level policy goals
Macro (System)	PRR funding; national innovation focus; emerging market diversification	Lack of national strategy; no registry; unequal funding structures; vendor dependence	System-level constraints shape institutional capacity and indirectly influence individual motivation and readiness

Table 8: Cross-Level Synthesis: Key Determinants of Robotic Surgery Adoption

A prominent cross-level theme concerns the misalignment between acquisition and readiness. While clinicians at the micro level consistently expressed strong motivation and perceived clinical value, their ability to develop and sustain robotic competence depended heavily on meso-level organisational structures. In several public hospitals, robotic systems were introduced before adequate teams, workflows or governance mechanisms were established, creating a gap between individual readiness and institutional capacity. As one surgeon summarised, *“We have the interest and the cases, but not the structure to grow”* (PS4).

This pattern reflects macro-level funding dynamics, where PRR-supported acquisitions were not systematically accompanied by long-term operational planning or workforce investment.

Variation in programme maturity also emerged as a central cross-level determinant of equity, access and professional development. High-volume centres, located mainly in the private sector and in a small number of public referral hospitals, benefited from stable scheduling, predictable caseloads and clear clinical leadership. These conditions enabled sustained learning and consistent outcomes. In contrast, fragmented programmes struggled to achieve continuity, resulting in skill decay, underutilisation and lower institutional confidence. This contrast demonstrates how meso-level organisation mediates the translation of micro-level motivation into routine practice.

Dependence on local champions constituted another recurring theme. Participants across sectors noted that committed clinical leaders played a critical role in initiating programmes, coordinating teams and mobilising institutional support. However, reliance on individual actors also created vulnerability, as programme sustainability weakened when champions changed roles or lacked administrative backing. This dependence reflects macro-level governance gaps, including the absence of national credentialing standards, centre-designation policies or coordinated oversight mechanisms.

Workforce shortages generated a clear cascade effect across analytical levels. National constraints in anaesthesiology and perioperative nursing limited operating room capacity at the meso level, thereby reducing procedural volume and training opportunities at the micro level. As one clinician observed, *"We want to expand, but without the staff we simply cannot open the room"* (PS3). These shortages directly affected learning continuity, professional confidence and patient safety, linking system-level challenges to individual experience.

Differences in digital maturity and data governance further reinforced cross-level disparities. Some private hospitals and high-volume public centres used dashboards and performance indicators to guide decision-making, while other institutions lacked the infrastructure to systematically monitor utilisation or outcomes. Clinicians in less mature settings reported uncertainty regarding oversight and risk management. International participants stressed that national registries and harmonised indicators are essential for transparency and continuous improvement. As one explained, *"Transparency is what drives improvement; without data, you are operating blind"* (IHP2).

Finally, the analysis revealed a tension between innovation-driven expansion and governance-driven caution. While clinicians expressed confidence in current robotic platforms and a desire to scale activity, many voiced concern about insufficient national guidance on training standards, credentialing and quality assurance. Ethical concerns identified at the micro level, particularly regarding premature autonomy and responsibility, intersected with organisational weaknesses and regulatory gaps. Industry representatives similarly emphasised that forthcoming AI-enabled functionalities will intensify the need for robust governance frameworks. As one noted, *"Hospitals need to be ready not only for the robot of today but for the software of tomorrow"* (IR3).

In synthesis, cross-level findings indicate that Portugal's capacity to integrate robotic surgery coherently depends on alignment between motivated professionals, supportive organisational structures and enabling national policies. Where these elements are misaligned, programmes remain fragile and uneven. Where alignment exists, robotic surgery evolves as a sustainable clinical capability.

4.4 Summary of Findings

The findings presented in this chapter demonstrate that the adoption of robotic-assisted surgery (RAS) in Portugal is shaped by the interaction of individual experience, organisational capacity and national health-system conditions. At the micro level, clinicians expressed strong motivation and perceived clinical value, viewing RAS as an important evolution in surgical practice. Confidence and skill development were closely linked to structured training and procedural volume, with participants consistently framing risk as a function of human and organisational factors rather than of the technology itself.

At the meso level, substantial variation emerged between hospitals. Private institutions and a small number of high-volume public centres benefited from clear leadership, predictable scheduling and greater investment in training, supporting programme continuity and maturation. In contrast, many public hospitals faced structural constraints, including workforce shortages, limited operating room availability and weak governance arrangements, which restricted utilisation and hindered professional development.

Macro-level dynamics further shaped these patterns. National funding mechanisms, particularly the PRR, accelerated robotic acquisition in the public sector but were not consistently accompanied by long-term investments in staffing, training or sustainability. Participants highlighted the absence of a national strategy for RAS, limited regulatory guidance, lack of a national registry and continued dependence on a dominant vendor, all of which contributed to uneven development across institutions.

All things considered, these findings show that the successful integration of robotic surgery in Portugal depends less on technological capability than on alignment among motivated professionals, supportive organisational structures, and coherent national governance. Misalignments across analytical levels generate fragmentation and inequity, while alignment enables programme stability and sustainable growth. The chapter therefore provides empirical answers to the research questions by clarifying how RAS is currently implemented, which factors shape adoption and how governance, organisational readiness and system-level conditions influence long-term sustainability. These insights form the basis for the discussion in the following chapter.

5. DISCUSSION

5.1 Shared Perceptions Across Stakeholder Groups

Across clinicians, managers, international experts and industry representatives, several areas of convergence emerged, revealing a relatively stable set of shared perceptions regarding the current and future landscape of robotic-assisted surgery in Portugal. A first point of consensus relates to the transformative potential of robotic systems for selected surgical procedures. Participants consistently highlighted perceived improvements in dexterity, precision, ergonomics and surgeon comfort, echoing findings from international research in contexts with long-standing robotic ecosystems (Autorino et al., 2014). Importantly, this perceived added value was not framed as universally applicable across all specialities or case types but rather as highly dependent on patient selection, institutional readiness and surgical volume. This suggests an emerging awareness that robotic surgery offers benefits under specific organisational and clinical conditions rather than by default (Negrut et al., 2024).

A second shared perception concerns the central role of surgical training and sustained practice volume. Both Portuguese and international clinicians emphasised that technical proficiency in robotic surgery requires formalised, structured learning pathways and ongoing exposure to maintain competency. Industry representatives reinforced this view by noting that even technologically advanced systems cannot compensate for inconsistent training or limited case throughput. Managers similarly recognised that without dedicated resources for continuous professional development, robotic programmes risk becoming inefficient or clinically unsafe.

A third element of convergence lies in the recognition of structural and organisational barriers that constrain the sustainable expansion of robotic surgery in Portugal. These include limited availability of trained personnel, insufficient integration of the operating room, lack of multidisciplinary team alignment, and the persistent misalignment between investment decisions and institutional capacity. Stakeholders agreed that introducing a robotic system without carefully planned workflow adaptation, technical support, and governance mechanisms can undermine both clinical performance and financial sustainability, a point also emphasised in the literature.

Ultimately, all groups expressed concern about the lack of a coherent national strategy for robotic surgery. Participants acknowledged that Portugal's rapid proliferation of robotic systems has occurred in a decentralised, largely uncoordinated manner, driven primarily by institutional-level decisions and industry dynamics rather than by a structured national framework. This shared perception underscores a broader understanding that the sustainability of robotic surgery requires coordinated planning that addresses inequity, resource duplication and variability in service quality.

In aggregate, these shared perceptions reveal an ecosystem that recognises both the opportunities and systemic constraints of robotic surgery. The convergence across diverse stakeholders strengthens the internal validity of the findings and provides a foundation for the interpretative analysis that follows.

5.2 Distinctive Views and Divergent Priorities

Despite significant areas of agreement, notable divergences emerged across stakeholder groups, reflecting differing professional roles, organisational pressures and strategic priorities. These distinctive views illuminate the complex sociotechnical dynamics surrounding robotic surgery adoption in Portugal (Barbash & Glied, 2010).

One of the clearest divergences concerns the perceived primary drivers of robotic adoption. Clinicians, particularly those with substantial hands-on experience, tended to emphasise clinical improvement, surgeon ergonomics and the long-term potential for innovation in minimally invasive surgery (MIS). Managers, however, frequently framed adoption within broader institutional considerations, including reputational positioning, competition within the private sector and strategic differentiation in high-demand specialities. Industry representatives acknowledged these institutional motivations but often articulated more optimistic narratives about long-term cost efficiencies and technological maturation. This divergence suggests that expectations around value and return on investment are unevenly distributed across the ecosystem (European Commission, 2021). This was further reflected in tensions between clinicians' professional development aspirations and managerial concerns regarding the high upfront costs and delayed return on investment associated with early-stage robotic programmes.

A second area of divergence relates to perceptions of equity and access. Clinicians and some managers voiced concerns that the current distribution of robotic systems may deepen disparities between public and private sectors, and between high- and low-volume centres. International experts, drawing on more mature ecosystems, highlighted the risks associated with fragmented deployment, warning that insufficient centralisation may compromise training quality and surgical outcomes. By contrast, industry representatives tended to emphasise the democratisation of technology and the benefits of expanding access, even in lower-volume contexts. These conflicting views expose tensions between commercial objectives, clinical safety and national health-system equity.

A third divergence concerns governance and accountability. Managers frequently stressed the organisational challenges of integrating robotics into existing structures, including procurement complexity, maintenance costs, data reporting and the need for clear performance indicators. Clinicians, however, tended to focus on the autonomy and conditions required to ensure safe and effective surgical practice. Industry stakeholders, meanwhile, viewed governance primarily through the lens of compliance, training delivery and technological support. These differing priorities reveal a lack of shared governance frameworks that align operational, clinical and technological dimensions.

Further divergences emerged in perceptions of Portugal's readiness to address emerging ethical challenges associated with robotic and AI-assisted surgery. International clinicians and some Portuguese experts expressed concerns about the absence of national guidelines for data use, credentialing, human–machine teaming and liability attribution. Industry representatives, while acknowledging the importance of ethical oversight, described these issues as downstream considerations to be addressed once adoption stabilises. This contrast highlights the need for proactive governance structures that anticipate ethical and regulatory demands rather than reacting to them post hoc.

Overall, these distinctive views do not merely represent disagreement; they illustrate the fragmented incentives and responsibilities that shape the current trajectory of robotic surgery in Portugal. Understanding these divergences is essential for designing coherent policy and organisational strategies that support sustainable, equitable and ethically grounded adoption.

5.3 Interpreting Portuguese Adoption Challenges Through International Comparison

Building on the international adoption patterns outlined in Section 2.3, this section positions the study's empirical findings within a comparative international perspective. This interpretative approach focuses on how differences in timing, pace and governance across health systems help interpret the Portuguese experience, rather than restating descriptive international trajectories.

Across health systems, robotic-assisted surgery adoption has followed divergent paths shaped by governance arrangements and the speed of expansion. Within the European Union, countries such as Sweden, the Netherlands and the United Kingdom generally pursued phased implementation supported by national coordination, volume centralisation and accreditation mechanisms. Empirical evidence from NHS robotic programmes shows that gradual rollout and institutional volume concentration supported safer learning curves and more consistent outcomes (Sheetz et al., 2020).

Portugal's trajectory contrasts with these phased approaches. Although robotic surgery was introduced later, diffusion occurred in a compressed and decentralised manner, with multiple hospitals acquiring systems within a short timeframe. Consequently, challenges related to training capacity, workflow integration and governance emerged simultaneously across institutions. From a comparative perspective, Portugal differs less in the nature of challenges encountered than in the pace at which they became visible. Comparison with early-adopting systems reinforces this interpretation.

In the United States, robotic surgery diffusion unfolded over more than a decade, allowing reimbursement models, credentialing practices and organisational routines to evolve alongside technological uptake, despite early periods of underutilisation (Barbash & Glied, 2010). In Japan, tighter coupling between reimbursement and credentialing supported more controlled expansion trajectories (Hara et al., 2024). In Portugal, similar organisational and governance tensions materialised within a much shorter period, intensifying system pressures.

At the individual level, Portuguese clinicians' perceptions closely mirror those reported internationally. Across contexts, enthusiasm for precision and ergonomics consistently coexists with concerns regarding learning curves, skill maintenance and increased workload during early adoption phases, particularly in low-volume settings (Pernar et al., 2017). These similarities suggest that individual reactions are not culturally specific but reflect common professional responses to complex technologies introduced under evolving organisational conditions.

International evidence highlights organisational readiness as central to successful robotic surgery adoption. Studies from Northern European systems emphasise leadership capacity, dedicated robotic programmes and integrated training pathways as key enablers (Aggarwal et al., 2022; Øvretveit et al., 2022). In Portugal, however, robotic systems were often acquired before such arrangements were fully consolidated, contributing to variability in readiness and utilisation.

Taken together, this comparison indicates that the Portuguese experience reflects widely observed adoption dynamics rather than exceptional responses. What distinguishes Portugal is the combination of late entry and accelerated scale-up, which intensified pressures on training, coordination and governance within a compressed timeframe. Situating Portugal as a late but accelerated adopter therefore provides a coherent lens for interpreting current challenges as predictable system-level tensions when technological diffusion outpaces institutional capacity.

5.4 Summary of Main Findings

The findings of this study reveal a complex and evolving landscape of robotic-assisted surgery in Portugal, characterised by shared understandings and divergent priorities among clinicians, managers, industry representatives and international experts. Taken together, the results portray an ecosystem that recognises the clinical promise of robotic surgery but faces significant organisational and systemic barriers that threaten its long-term sustainability.

At the micro level, participants highlighted strong perceived benefits of robotic surgery, including improved surgeon ergonomics, greater precision, and better procedural control. These advantages, however, were consistently framed as contingent upon adequate training, structured learning pathways, and sufficient procedural volume. The shared recognition that robotic proficiency cannot be achieved or maintained in low-volume contexts underscores the vulnerability of Portugal's current decentralised expansion. Moreover, clinicians pointed to persistent disparities in exposure, certification and access to training opportunities, which contribute to variation in readiness across specialities and institutions.

At the meso level, organisational dynamics emerged as a central determinant of adoption success. Managers and clinicians described a misalignment between investment decisions and institutional capacity, particularly regarding staffing resources, workflow integration, multidisciplinary team coordination and ongoing operational costs. Many institutions introduced robotic systems without parallel investment in training, simulation, data infrastructure or cross-departmental governance processes. As a result, hospitals often rely on informal workarounds to sustain robotic activity, creating operational fragility and undermining the reliability of performance evaluation. The divergence between clinical aspirations and organisational realities highlights the need for structured internal governance and long-term planning.

At the macro level, the findings point to systemic gaps that shape the national trajectory of robotic surgery. Portugal's expansion has occurred in the absence of a coordinated national strategy, leading to irregular distribution of robotic systems, limited oversight of investment decisions and inconsistent definitions of quality standards. International experts highlighted the risks of such fragmentation, noting parallels with early-stage adoption patterns in other countries that ultimately required corrective policy intervention. Industry representatives, while supportive of expansion, acknowledged that Portugal lacks a regulatory and training ecosystem comparable to those of more mature markets, particularly regarding credentialing pathways, data governance, and frameworks for ethical AI integration.

A cross-cutting finding concerns the tension between technological optimism and structural readiness. While stakeholders generally agreed on the clinical potential of robotic systems, they differed in their expectations regarding cost-efficiency, accessibility and the speed at which hospitals and clinicians can realistically adapt. This tension is amplified by competing incentives: private hospitals to differentiate themselves, public hospitals face resource constraints, and industry actors operate under global commercial pressures. These dynamics collectively produce a fragmented adoption pathway that risks entrenching inequalities and undermining the technology's sustainability.

Finally, the results highlight a widely shared acknowledgement that Portugal lacks clear governance mechanisms, standardised performance metrics, ethical guidelines, and national coordination to support safe and equitable expansion. Despite differences in emphasis, all stakeholder groups recognised the need for a more coherent national framework to guide deployment, training, evaluation and long-term stewardship of robotic-assisted surgery.

On the whole, these findings suggest that the challenges facing robotic surgery in Portugal are not solely technical but deeply sociotechnical, emerging from interactions between individual skills, organisational structures and systemic governance. Section 5.4 will build on these insights to propose a framework for sustainable and ethically grounded adoption (Greenhalgh et al., 2017).

5.5 A Framework for Sustainable and Ethical Robotic Surgery Adoption in Portugal

Building on the conceptual framework introduced in the Background (see **Figure 4**), the proposed framework reflects patterns identified in international research, highlighting the role of sequencing, governance coherence and organisational preparedness in shaping robotic surgery adoption (Greenhalgh et al., 2017; Greenhalgh & Papoutsi, 2018; Øvretveit et al., 2022).

Figure 9 revisits and empirically grounds this multilevel framework, integrating the micro (individual), meso (organisational), and macro (system-level) determinants identified in the results, and situating them within the broader contextual and outcome layers that influence implementation.

The model positions robotic surgery adoption as a sociotechnical process influenced simultaneously by individual perceptions and skills, organisational governance and capacity, and national policy, regulation and ecosystem maturity. By visually mapping these relationships, **Figure 9** highlights the need for alignment across levels, showing how weaknesses in any one domain can compromise sustainability, equity and safety. The processual dimension of the model further emphasises that adoption is not a single event but an evolving sequence that requires continuous evaluation, adaptation and governance.

This framework provides the conceptual basis for the following sub-sections, in which the micro, meso and macro levels are examined in detail in light of the empirical findings.

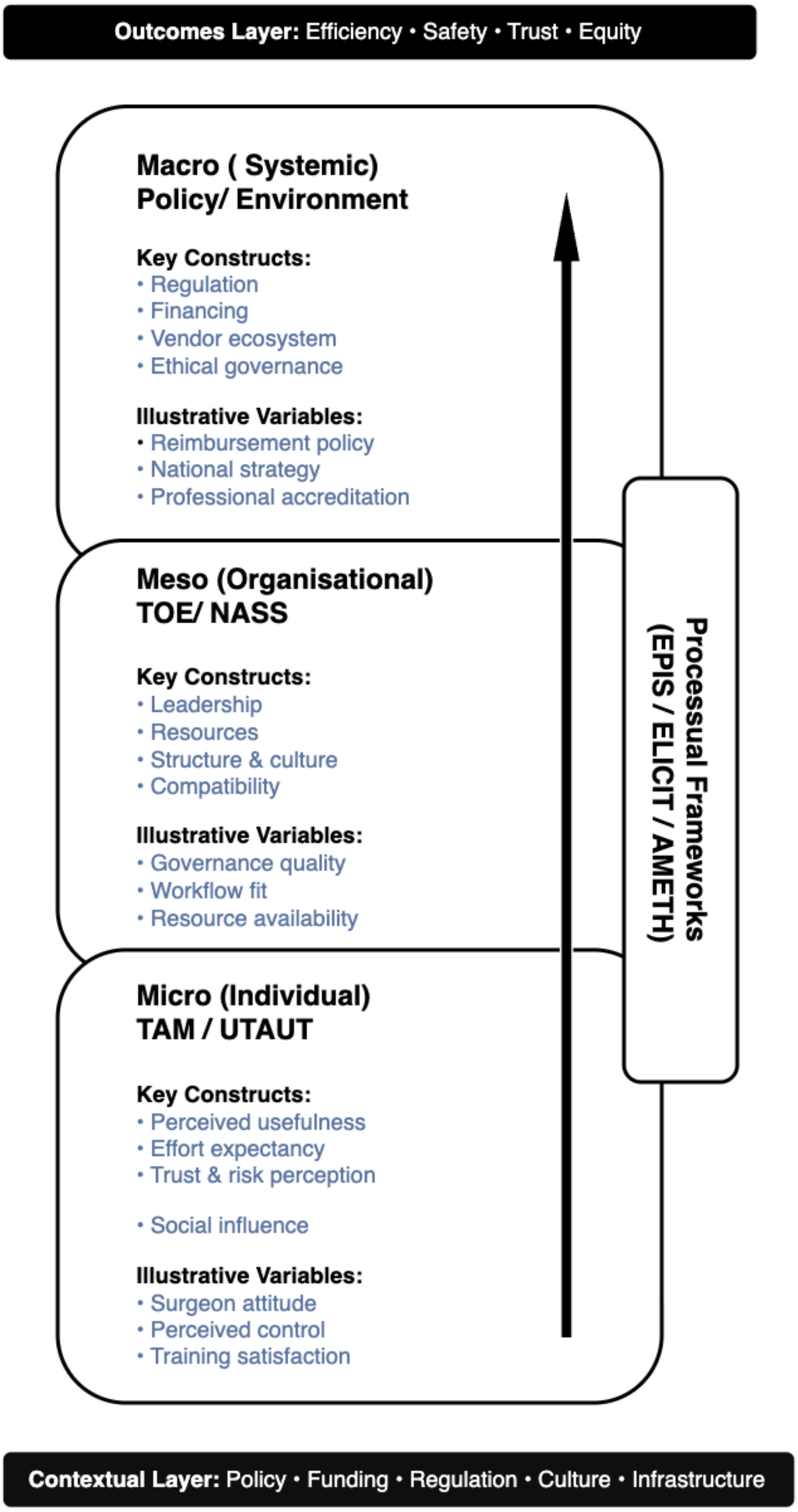

Figure 9: Multilevel Sociotechnical Framework for Robotic-Assisted Surgery Adoption in Portugal

5.5.1 Micro-Level Dimension: Clinical Proficiency, Safety and Professional Development

At the micro level, sustainable adoption requires strengthening the individual and professional foundations upon which robotic surgery depends. The findings clearly demonstrate that clinical proficiency is contingent upon structured training pathways, adequate procedural volume and continuous skill reinforcement. This implies the need for nationally recognised certification routes, consistent simulation-based training opportunities and protected time for surgeons to maintain expertise. Additionally, ensuring that robotic systems are used in contexts where they genuinely add value is essential for safeguarding patient safety and avoiding unnecessary technological dependence. The framework, therefore, emphasises clinical appropriateness, surgeon readiness and multi-professional team alignment as core micro-level determinants.

5.5.2 Meso-Level Dimension: Organisational Capacity, Governance and Operational Integration

At the organisational level, hospitals must ensure that robotic adoption is embedded in coherent governance and operational structures. The study revealed gaps in workflow integration, resource allocation, data systems, multidisciplinary coordination and long-term investment planning. In response to these findings, the framework highlights four recurring organisational dimensions associated with readiness for robotic surgery: strategic alignment, operational infrastructure, team-based governance and performance monitoring. Hospitals must adopt transparent governance mechanisms that define responsibilities across clinical, managerial and technical domains, supported by routine data collection and evaluation. Equally important is the integration of robotic systems into existing workflows, which requires OR scheduling adaptations, technical support availability, and interdepartmental collaboration. Without these meso-level components, robotic programmes risk becoming inefficient, unsafe or financially unsustainable.

5.5.3 Macro-Level Dimension: National Strategy, Equity and Ethical Stewardship

At the macro level, the framework highlights the urgent need for coordinated national policies that provide strategic direction for robotic surgery. The current decentralised expansion has resulted in uneven distribution, variable training conditions and potential inequities between public and private sectors. A national strategy should therefore define criteria for system allocation, establish minimum volume thresholds, outline quality and safety metrics and ensure equitable access across regions. Furthermore, as robotic systems increasingly integrate digital tools and AI-enhanced capabilities, Portugal must proactively define ethical and regulatory guidelines for data governance, algorithmic transparency, liability attribution, and patient consent. Accordingly, these ethical considerations cannot remain secondary or reactive; they must be embedded as core elements of the national governance architecture.

5.5.4 Cross-Level Integration: Aligning Incentives and Building Systemic Coherence

A central insight from this study is that misalignment across micro, meso and macro levels undermines the sustainability of robotic surgery. For instance, surgeons may be trained but lack institutional support; hospitals may acquire systems without sufficient clinical volume; or national policy may lag behind technological deployment. The framework therefore emphasises the need for alignment across levels through mechanisms such as shared decision-making, integrated planning, transparent reporting and coordinated stakeholder engagement. Creating feedback loops between clinicians, managers, regulators and industry can help ensure that robotic adoption evolves in a coherent and sustainable manner.

5.5.5 Positioning the Framework as a Contribution to Practice and Research

By integrating clinical, organisational and systemic factors, the proposed framework advances existing discussions on surgical innovation and sociotechnical adoption in several ways. First, it moves beyond linear or technology-centric explanations by emphasising interdependencies across system levels. Second, it incorporates ethical stewardship as a core dimension rather than a peripheral consideration. Third, it provides a practical structure that can inform policy development, hospital decision-making, professional training strategies and future empirical research.

In general, the framework presented here offers a comprehensive, actionable and theoretically grounded perspective for guiding the next phase of robotic surgery adoption in Portugal. It recognises the clinical promise of robotic systems but situates that promise within the organisational and systemic realities that ultimately determine whether the technology delivers its intended value.

Taken together, these comparisons indicate that the challenges identified in Portugal are not exceptional, but their intensity reflects the interaction between late entry, compressed expansion and heterogeneous institutional capacity. Sociotechnical perspectives help explain how similar technologies yield different outcomes depending on governance structures, organisational preparedness and the sequencing of implementation. Portugal thus represents a particularly instructive case for understanding how multilevel determinants shape robotic-assisted surgery adoption under accelerated conditions.

5.6 Addressing the Research Questions

This study was guided by three research questions that explored the perceptions, conditions and system-level requirements for the sustainable adoption of robotic-assisted surgery in Portugal. The findings presented throughout this chapter allow for a direct response to each of these questions.

RQ1: How do stakeholders perceive the current landscape and future trajectory of robotic-assisted surgery in Portugal?

The study finds that stakeholders share a broadly positive view of the clinical potential of robotic surgery, especially regarding precision, ergonomics and innovation capacity. However, there is also widespread recognition that these benefits are contingent on structured training, sustained procedural volume and adequate organisational support. Distinctive perspectives emerge among clinicians, managers, international experts and industry representatives, revealing differing priorities regarding access, equity, investment rationale and long-term sustainability. Regarding the future trajectory, stakeholders described an expected evolution towards greater technological mediation of surgical practice, including the integration of AI-supported functionalities in decision making and the longer-term possibility of remote or semi-remote surgical models enabling cross-border operations through robotic systems. These developments were not framed as distant or speculative, but as foreseeable extensions of current capabilities, contingent on advances in governance, regulation, connectivity and training.

RQ2: What organisational and systemic factors influence the sustainable adoption of robotic-assisted surgery in Portugal?

The results demonstrate that adoption is shaped by interdependent micro-, meso- and macro-level determinants. At the micro level, clinical proficiency and surgeon readiness are essential. At the meso level, organisational governance, workflow integration, resource allocation and performance monitoring play critical roles. At the macro level, the absence of a coordinated national strategy, uneven distribution of systems, policy gaps, and emerging ethical and regulatory challenges create systemic constraints. These interconnected factors collectively informed the multilevel framework presented in Section 5.4.

RQ3: What strategies could support a more equitable, safe and ethically grounded expansion of robotic surgery in Portugal?

The study identifies a set of targeted strategies across policy, organisational, training and industry domains. These include the establishment of a national framework defining standards for robotic surgery, the strategic allocation of robotic systems to appropriately selected hospitals, and the designation of reference centres with procedure-specific specialisation to ensure sufficient volume, expertise and quality of care. Complementary strategies include the standardisation of credentialing pathways, the strengthening of organisational readiness assessments, the development of multidisciplinary governance structures, and the integration of ethical and data-governance principles into technological design and regulation. Together, these strategies outline a pathway for coherent, equitable and sustainable expansion.

Overall, the findings comprehensively address the research questions by offering an integrated understanding of stakeholder perceptions, sociotechnical determinants, and actionable strategies that can support Portugal in advancing robotic-assisted surgery in a safe, equitable, and ethically grounded manner.

5.7 Study Limitations

Although this study provides a comprehensive and multi-level analysis of robotic-assisted surgery in Portugal, several limitations must be acknowledged. First, the findings are based on a purposive sample of clinicians, managers, industry representatives and international experts. While this approach was essential for accessing specialised knowledge, the perspectives captured do not represent the full diversity of institutions or professional experiences within the Portuguese health system. The interpretations presented here, therefore, reflect informed but situated viewpoints.

Second, the qualitative nature of the study means that the results rely on participants' perceptions, interpretations and subjective experiences. These insights are invaluable for understanding the sociotechnical dynamics of adoption but cannot be treated as direct indicators of clinical performance, economic outcomes or system-wide effectiveness. Future studies combining qualitative insights with quantitative metrics would strengthen the evidence base.

Third, access to international clinicians and industry representatives was uneven, which may have influenced the comparative depth of the analysis. Although the inclusion of these perspectives enriched the findings, broader representation across companies, markets and national ecosystems would provide a more comprehensive view of global trends.

Finally, the rapidly evolving nature of robotic and AI-enabled surgical technologies means that some insights may shift over time as systems mature, regulatory frameworks evolve and training pathways develop. This study captures a specific moment in Portugal's adoption trajectory, and ongoing monitoring will be necessary to understand long-term impacts.

Despite these limitations, the triangulation of stakeholder perspectives and the integration of micro, meso and macro analyses reinforce the robustness of the findings and provide a solid foundation for the recommendations that follow.

5.8 Recommendations

The findings of this study highlight the need for coordinated action across policy, organisational and professional domains to ensure that robotic-assisted surgery in Portugal evolves in a sustainable, equitable and ethically grounded manner. The recommendations presented below draw directly on the multilevel framework developed in this dissertation and translate its core insights into actor-specific recommendations targeting the key actors shaping the national trajectory of robotic surgery.

5.8.1 For Policymakers and National Health Authorities

Policymakers and national health authorities in Portugal play a central role in shaping the strategic, regulatory and financing conditions for the adoption of robotic-assisted surgery. The development of a coordinated national strategy should therefore be led at ministerial level, with clearly defined responsibilities across key public entities within the Portuguese health system.

The Directorate-General of Health (Direção-Geral da Saúde – **DGS**) should be responsible for issuing national clinical and organisational guidelines for robotic-assisted surgery, including indications, safety standards, training requirements and ethical considerations, supporting consistency in clinical practice. The Central Administration of the Health System **(**Administração Central do Sistema de Saúde – **ACSS**) must coordinate strategic planning and financing, including system allocation criteria, minimum-volume thresholds and funding mechanisms that reflect the full lifecycle costs of robotic programmes.

The Health Regulatory Authority (Entidade Reguladora da Saúde – **ERS**) has a key role in harmonising evaluation criteria for robotic-surgery equipment across public and private sectors, promoting equity, transparency and coherence in adoption decisions. The Shared Services of the Ministry of Health (Serviços Partilhados do Ministério da Saúde **–** **SPMS**) can support data governance through standardised reporting, interoperability and national benchmarking. These measures are particularly relevant for strengthening the capacity of the National Health Service (Serviço Nacional de Saúde – **SNS**) to deliver equitable access to robotic-assisted surgery while maintaining quality, safety and sustainability.

As robotic systems increasingly integrate AI-driven functionalities, coordinated regulatory approaches addressing data governance, algorithmic transparency and liability attribution will be essential to safeguard patient rights and public trust.

5.8.2 For Hospital Leaders and Implementers

Hospitals should embed robotic adoption within structured governance mechanisms that define roles, responsibilities and performance metrics across clinical, managerial and technical teams. Organisational readiness assessments should be carried out before procurement decisions, evaluating workflow compatibility, staffing requirements, IT infrastructure and long-term sustainability. Implementers should focus on creating dedicated robotic surgery programmes that include multidisciplinary teams, protected training time and continuous monitoring of outcomes. Investment decisions must be aligned with realistic procedural volumes and strategic goals to avoid underutilisation and inefficiency. Hospitals should also strengthen data collection and reporting practices to inform internal decision-making and contribute to national benchmarking initiatives.

5.8.3 For Clinicians, Training Bodies and Professional Associations

Clinicians, training bodies and professional associations play a critical role in establishing standardised and credible pathways for robotic surgical education. In the Portuguese context, the **Ordem dos Médicos**, in articulation with specialty colleges and professional associations dedicated to robotic surgery, namely the Associação Portuguesa de Cirurgia Robótica **(APCiR)** and the Sociedade Portuguesa de Cirurgia Robótica **(SPCR)**, is well positioned to contribute to the definition of competency-based training milestones, certification requirements and professional standards for robotic-assisted surgery. These organisations can support the integration of simulation-based training, structured proctoring and supervised clinical progression into early-stage robotic education, while promoting mentorship networks that reduce variability in learning opportunities across institutions. The development of national-level credentialing processes would further enhance consistency in proficiency and patient safety across specialties and hospital settings. Professional associations can also play a key role in disseminating evidence-informed guidelines on case selection, ergonomics, team coordination and troubleshooting, as well as in advocating for policies that ensure equitable access to training resources.

Strengthening collaboration between Portuguese and international centres of excellence may accelerate skill acquisition and promote harmonisation with global standards.

5.8.4 For Industry and Technology Developers

Industry stakeholders should work collaboratively with healthcare institutions to support training, troubleshoot technical challenges, and ensure system interoperability within existing hospital infrastructures. Transparent communication regarding maintenance requirements, data-handling practices, and long-term costs is essential for informed organisational decision-making. As robotic systems increasingly incorporate AI-driven features, industry partners should prioritise ethical design principles, including explainability, data minimisation and robust cybersecurity safeguards. Developers can also contribute to equitable adoption by supporting training initiatives in lower-volume centres and by engaging in co-development processes that incorporate clinician and patient feedback early in the design cycle. Building long-term partnerships rather than transactional relationships will help align commercial objectives with broader health-system goals (Mittelstadt, 2019).

5.9 Future Research

Future research on robotic-assisted surgery in Portugal should expand beyond the qualitative insights provided in this study to build a more comprehensive, multidimensional evidence base. First, quantitative analyses are needed to examine clinical outcomes, cost-effectiveness and long-term performance metrics across institutions and specialities. Such studies would complement the perceptual insights captured here and allow for comparisons between robotic, laparoscopic and open approaches using robust empirical indicators.

Second, longitudinal research tracking hospitals over time would provide valuable information on how robotic programmes evolve, how learning curves stabilise and how organisational and financial sustainability develop across different contexts. This type of research could also reveal which governance structures and training strategies are most effective in sustaining safe and efficient practice.

Third, comparative studies involving countries with more mature robotic ecosystems would offer important lessons regarding centralisation, accreditation pathways, funding models and regulatory oversight. Understanding how Portugal's experience aligns with or diverges from these contexts could support more evidence-informed policymaking.

Fourth, as robotic systems integrate AI-enabled functionalities, future investigations should explore ethical, legal and data-governance challenges in greater depth. Topics such as algorithmic accountability, human–machine teaming, liability attribution and patient perceptions of AI-assisted surgery remain underexplored and are likely to gain prominence as technologies evolve.

Finally, participatory studies that include patients, trainees, nurses and other allied professionals would enrich the understanding of how robotic surgery affects the broader care pathway. Incorporating these voices will be crucial to designing policies and organisational strategies that support equitable, human-centred adoption.

Together, these avenues of future research can help strengthen the national evidence base and guide the strategic planning necessary for Portugal to achieve a safe, efficient and ethically grounded expansion of robotic-assisted surgery.

6. CONCLUSION

6.1 Overview of the Study

This dissertation examined the adoption of robotic-assisted surgery in Portugal through a multilevel sociotechnical lens, integrating perspectives from clinicians, managers, industry representatives and international experts. By combining empirical findings with theoretical frameworks on innovation adoption, organisational governance and ethical health technology, the study explored how individual, organisational and systemic factors interact to shape the current and future trajectory of robotic surgery. The research addressed three central questions concerning stakeholder perceptions, determinants of sustainable adoption and strategies for ethically grounded expansion. The analysis revealed an ecosystem marked by both enthusiasm for the transformative potential of robotic surgery and significant misalignments that constrain its sustainable implementation.

6.2 Key Contributions

Empirical Contributions

The study provides one of the most comprehensive qualitative mappings of the Portuguese robotic-surgery landscape to date. It identifies shared perceptions across stakeholder groups regarding clinical potential, training requirements and systemic gaps, while also highlighting divergent priorities linked to institutional pressures, market dynamics and equity considerations. These insights offer a rich understanding of how robotic surgery is experienced and negotiated in Portugal's heterogeneous health system.

Theoretical Contributions

A central theoretical contribution is the development of the multilevel sociotechnical framework presented in Chapter 5, which synthesises micro, meso and macro determinants of robotic-surgery adoption. This model integrates concepts from TAM, UTAUT, TOE and ethical governance frameworks, positioning robotic surgery as a dynamic and interdependent system rather than a technological upgrade. The framework provides a foundation for future empirical evaluation and offers a structure that can be adapted to other emerging technologies in surgical practice.

Practical and Policy Contributions

The study generates actionable recommendations for policymakers, hospital leaders, training bodies and industry stakeholders. These include the need for national strategic planning, standardised credentialing pathways, organisational readiness assessments and ethical oversight of data and AI-enabled functionalities. Collectively, these contributions highlight how evidence-based, coordinated efforts can support safe, equitable and sustainable expansion.

6.3 Implications for the Future of Robotic Surgery in Portugal

The findings underscore that Portugal's rapid but decentralised adoption trajectory presents both opportunities and risks. Without coherent national governance, disparities in access, training and quality may deepen, potentially undermining patient outcomes and long-term sustainability. Conversely, if stakeholders align around coordinated planning, transparent governance structures and investment in training and evaluation, Portugal is well positioned to leverage robotic surgery as a driver of innovation and clinical excellence. The integration of emerging AI-driven functionalities further heightens the need for proactive ethical and regulatory frameworks to ensure public trust and safeguard patient rights. This dissertation demonstrates that the success of robotic surgery depends not only on the technology itself but on the ecosystem that supports it.

6.4 Final Reflection

This study illustrates the importance of examining technological innovation in healthcare through a sociotechnical and ethically grounded perspective. Robotic-assisted surgery offers substantial potential, yet its value can only be realised when adoption is accompanied by strategic planning, organisational readiness, professional development and responsible governance. By integrating multiple stakeholder perspectives and proposing a structured framework for action, this dissertation contributes to an informed dialogue on how Portugal can advance robotic surgery in a way that is clinically meaningful, organisationally sustainable and socially responsible. Future developments in robotics and AI will undoubtedly reshape surgical practice, making it essential that policy, training and governance mechanisms evolve in tandem. The hope is that this work supports these ongoing efforts and informs the next steps toward a mature and equitable robotic-surgery ecosystem in Portugal.

REFERENCES

Aggarwal, R., Mytton, O. T., Derbrew, M., Grantcharov, T. P., & Darzi, A. (2022). Training and simulation for patient safety in robotic surgery. *British Journal of Surgery, 109*(6), 505–513. https://doi.org/10.1093/bjs/znac066

Appelbaum, S. H., Habashy, S., Malo, J. L., & Shafiq, H. (2012). Back to the future: Revisiting Kotter's 1996 change model. *Journal of Management Development, 31*, 764–782. https://doi.org/10.1108/02621711211253231

Autorino, R., Zargar, H., & Kaouk, J. H. (2014). Robotic-assisted laparoscopic surgery: Recent advances in urology. *Fertility and Sterility, 102*(4), 939–949. https://doi.org/10.1016/j.fertnstert.2014.05.033

Barbash, G. I., & Glied, S. A. (2010). New technology and health care costs—The case of robot-assisted surgery. *New England Journal of Medicine, 363*(8), 701–704. https://doi.org/10.1056/NEJMp1006602

Beier, M., & Früh, S. (2020). Technological, organizational, and environmental factors influencing social media adoption by hospitals in Switzerland: Cross-sectional study. *Journal of Medical Internet Research, 22*(3), e16995. https://doi.org/10.2196/16995

Blumer, H. (1954). What is wrong with social theory? *American Sociological Review, 19*(1), 3–10. https://doi.org/10.2307/2088165

Bowen, G. A. (2006). Grounded theory and sensitizing concepts. *International Journal of Qualitative Methods, 5*(3), 12–23. https://doi.org/10.1177/160940690600500304

Brar, A., Ashrafian, H., Darzi, A., & Athanasiou, T. (2024). Public perceptions and misconceptions of robotic-assisted surgery. *Journal of Robotic Surgery*, 18(4), 1371–1378. https://doi.org/10.1007/s11701-024-01837-6

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Burke, E., Devine, M., Harkins, P., Fenn, S., Khan, M. F., & McGuire, B. B. (2025). Robotic surgery governance structures: A systematic review. *Journal of Robotic Surgery, 19*(1), 218. https://doi.org/10.1007/s11701-025-02356-8

Cabitza, F., Rasoini, R., & Gensini, G. F. (2017). Unintended consequences of machine learning in medicine. *JAMA, 318*(6), 517–518. https://doi.org/10.1001/jama.2017.7797

Carrola Gomes, D., Athayde Nemésio, R., Rodrigues, S., Penedo, J., & Paixão, I. (2024). Robotic colorectal surgery: Analysis of the first three years of activity in a hospital of the Portuguese National Health Service. Acta Médica Portuguesa, 37(7–8), 535–540. https://doi.org/10.20344/amp.20204

Castillo-Montoya, M. (2016). Preparing for interview research: The interview protocol refinement framework. *The Qualitative Report, 21*(5), 811–831. https://doi.org/10.46743/2160-3715/2016.2337

Childers, C. P., & Maggard-Gibbons, M. (2018). Estimation of the acquisition and operating costs for robotic surgery. *JAMA, 320*(8), 835–836. https://doi.org/10.1001/jama.2018.9219

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design* (4th ed.). Sage.

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

Dzindolet, M. T., Peterson, S. A., Pomranky, R. A., Pierce, L. G., & Beck, H. P. (2003). The role of trust in automation reliance. *International Journal of Human-Computer Studies, 58*(6), 697–718.

Edmondson, A. C. (1999). Psychological safety and learningcbehavior in work teams. *Administrative Science Quarterly, 44*(2), 350–383.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review, 14*(4), 532–550. https://doi.org/10.5465/amr.1989.4308385

European Commission. (2021). *Impact assessment accompanying the proposal for a regulation laying down harmonised rules on artificial intelligence (Artificial Intelligence Act)* (SWD(2021) 84 final). Publications Office of the European Union.

ERSC – European Robotics Strategy Consortium. (2024). *Strategic governance of surgical robotics in Europe*. European Commission.

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods, 5*(1), 80–92. https://doi.org/10.1177/160940690600500107

Floridi, L. (2018). Soft ethics and the governance of the digital. *Philosophy & Technology, 31*(1), 1–8. https://doi.org/10.1007/s13347-018-0303-9

Gonçalves, M. R., de Matos, J. N., Oliveira, A., Marinho, R., Cadime, I., Alves, P. C., Morales-Conde, S., & Castelo-Branco, M. (2023). Robotic4all project: Results of a hands-on robotic surgery training program. *Laparoscopic, Endoscopic and Robotic Surgery*, 6, 100105. https://doi.org/10.1016/j.lers.2023.01.002

Greenhalgh, T., & Papoutsi, C. (2018). Studying complexity in health services research. *BMC Medicine, 16*, 95. https://doi.org/10.1186/s12916-018-1089-4

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? *Field Methods, 18*(1), 59–82. https://doi.org/10.1177/1525822X05279903

Haltaufderheide, J., Pfisterer-Heise, S., Pieper, D., & Ranisch, R. (2025). The ethical landscape of robot-assisted surgery: A systematic review. *Journal of Robotic Surgery*, 19(1), Article 102. https://doi.org/10.1007/s11701-025-02228-1

Hara, K., Kanda, M., Kuwabara, H., Kobayashi, Y., & Inoue, T. (2024). Current status analysis of the prevalence and regional disparities of robot-assisted laparoscopic prostatectomy in Japan using diagnosis procedure combination data. *Scientific Reports, 14*, 24823. https://doi.org/10.1038/s41598-024-75837-9

Hashimoto, T., Yoshioka, K., Gondo, T., Kamoda, N., Satake, N., Ozu, C., Horiguchi, Y., Namiki, K., Nakashima, J., & Tachibana, M. (2013). Learning curve and perioperative outcomes of robot-assisted radical prostatectomy in 200 initial Japanese cases by a single surgeon. *Journal of Endourology, 27*(10), 1212–1218. https://doi.org/10.1089/end.2013.0235

Heinsch, M., Wyllie, J., Carlson, J., Wells, H., Tickner, C., & Kay-Lambkin, F. (2021). Theories informing eHealth implementation: Systematic review and typology classification. *Journal of Medical Internet Research, 23*(5), e18500. https://doi.org/10.2196/18500

Higgins, R. M., Frelich, M. J., Bosler, M. E., & Gould, J. C. (2017). Cost analysis of robotic versus laparoscopic general surgery procedures. *Surgical Endoscopy, 31*(1), 185–192. https://doi.org/10.1007/s00464-016-4954-2

Hirri, F., Pickering, O. J., Carter, N. C., van Boxel, G. I., & Pucher, P. H. (2024). Learning curves for adoption of robotic bariatric surgery: A systematic review of safety, efficiency and clinical outcomes. *Obesity Surgery*. https://doi.org/10.1007/s11701-024-02100-8

Holmes, W., Bialik, M., & Fadel, C. (2023). Artificial intelligence in education. In *AI ethics: Global perspectives* (pp. 621–653). Globethics Publications. https://doi.org/10.58863/20.500.12424/4276068

Hull, L., Arora, S., Aggarwal, R., Darzi, A., & Vincent, C. (2012). The impact of nontechnical skills on technical performance in surgery: A systematic review. *Journal of the American College of Surgeons, 214*(2), 214–230. https://doi.org/10.1016/j.jamcollsurg.2011.10.016

Iversen, T., & Anell, A. (2016). Coordination of health care in the Nordic countries. *Nordic Journal of Health Economics, 4*(1), 41–58. https://doi.org/10.5617/njhe.2846

Kotter, J. P. (1996). *Leading change*. Harvard Business School Press.

Kvale, S., & Brinkmann, S. (2015). *InterViews: Learning the craft of qualitative research interviewing* (3rd ed.). Sage.

Lane, T. (2018). A short history of robotic surgery. *Annals of the Royal College of Surgeons of England, 100*(Suppl 7), 5–7. https://doi.org/10.1308/rcsann.supp1.5

Lai, T.-J., Roxburgh, C., Boyd, K. A., & Bouttell, J. (2024). Clinical effectiveness of robotic versus laparoscopic and open surgery: An overview of systematic reviews. *BMJ Open, 14*(9), e076750. https://doi.org/10.1136/bmjopen-2023-076750

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage.

Marcus, H. J., Ramirez, P. T., Khan, D. Z., et al. (2024). The IDEAL framework for surgical robotics: Development, comparative evaluation and long-term monitoring. *Nature Medicine, 30*, 61–75. https://doi.org/10.1038/s41591-023-02732-7

McCulloch, P., Altman, D. G., Campbell, W. B., et al. (2009). No surgical innovation without evaluation: The IDEAL framework. *The Lancet, 374*(9695), 1105–1112. https://doi.org/10.1016/S0140-6736(09)61116-8

Mendes, C. (2025). Segurança em Cirurgia Robótica In Gabinete de Segurança do Doente (Coord.). *Segurança do Doente: da teoria à prática.* Newsletter Eventos da Semana. Edição nº 288. Lisboa: Unidade Local de Saúde São José.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook*. Sage.

Ministry of Health, Labour and Welfare. (2022). *Reimbursement approvals for robot-assisted surgical procedures in Japan*. Government of Japan.

Mittelstadt, B. D. (2019). Principles alone cannot guarantee ethical AI. *Nature Machine Intelligence, 1*(11), 501–507. https://doi.org/10.1038/s42256-019-0114-4

Moor, J. H. (2006). The nature, importance, and difficulty of machine ethics. *IEEE Intelligent Systems, 21*(4), 18–21. https://doi.org/10.1109/MIS.2006.80

Morrell, A. L. G., Morrell-Júnior, A. C., Morrell, A. G., Mendes, J. M. F., Tustumi, F., De-Oliveira-e-Silva, L. G., & Morrell, A. (2021). The history of robotic surgery and its evolution: When illusion becomes reality. *Revista do Colégio Brasileiro de Cirurgiões, 48*, e20202798. https://doi.org/10.1590/0100-6991e-20202798

Negrut, R. L., Cote, A., Caus, V. A., & Maghiar, A. M. (2024). Systematic review and meta-analysis of laparoscopic versus robotic-assisted surgery for colon cancer: Efficacy, safety, and outcomes—A focus on studies from 2020–2024. *Cancers, 16*(8), 1552. https://doi.org/10.3390/cancers16081552

Oliver Wyman. (2023). *Positioning the industry for growth in robotic surgery*. Oliver Wyman Health & Life Sciences.

Organisation for Economic Co-operation and Development. (2024). *Addressing high-cost medical technologies in publicly funded health systems*. OECD Publishing.

Øvretveit, J., Shekelle, P. G., Dy, S. M., McDonald, K. M., Hempel, S., Pronovost, P. J., Rubenstein, L. V., Taylor, S. L., Foy, R., & Wachter, R. M. (2022). Aligning quality improvement efforts and policy goals in a national integrated health system. *International Journal of Health Policy and Management, 11*(11), 2544–2553. https://doi.org/10.1111/1475-6773.13944

Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Sage.

Pernar, L. I. M., Robertson, F. C., Tavakkoli, A., Sheu, E. G., Brooks, D. C., & Smink, D. S. (2017). An appraisal of the learning curve in robotic general surgery. *Surgical Endoscopy, 31*(6), 2453–2461. https://doi.org/10.1007/s00464-017-5520-2

Power, C. (2024). Ethical considerations in the era of artificial intelligence, automation, and surgical robots. *Discover Artificial Intelligence*, 4, Article 6. https://doi.org/10.1007/s44163-024-00166-9

Rahimi, B., Nadri, H., Afshar, H. L., & Timpka, T. (2018). A systematic review of the technology acceptance model in health informatics. *Applied Clinical Informatics, 9*(3), 604–634. https://doi.org/10.1055/s-0038-1668091

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Royal College of Surgeons of England. (2023). *Robotic-assisted surgery: A pathway to the future*. Royal College of Surgeons of England.

Scarbrough, H., & Kyratsis, Y. (2021). From spreading to embedding innovation in health care: Implications for theory and practice. *Health Care Management Review*, 47(3), 236–244. https://doi.org/10.1097/HMR.0000000000000323

Sheetz, K. H., et al. (2020). Trends in the adoption of robotic surgery for common surgical procedures. *JAMA Network Open, 3*(1), e1918911. https://doi.org/10.1001/jamanetworkopen.2019.18911

Sridhar, A. N., Briggs, T. P., Kelly, J. D., & Nathan, S. (2017). Training in robotic surgery: An overview. *Current Urology Reports, 18*(8), 62. https://doi.org/10.1007/s11934-017-0710-y

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

Trastulli, S., Cirocchi, R., Desiderio, J., Coratti, A., Guarino, S., Renzi, C., Corsi, A., Boselli, C., Santoro, A., Minelli, L., & Parisi, A. (2015). Robotic versus laparoscopic approach in colonic resections for cancer and benign diseases: A systematic review and meta-analysis. *Surgical Endoscopy, 29*(12), 3636–3649. https://doi.org/10.1007/s00595-019-1763-y

Van Wynsberghe, A. (2021). *AI ethics*. Oxford University Press.

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

World Health Organization Regional Office for Europe. (2023). *Digital health in the WHO European region: The ongoing journey to commitment and transformation*.

Zou, J., Zhu, H., Tang, Y., Huang, Y., Chi, P., & Wang, X. (2025). Robotic versus laparoscopic surgery for rectal cancer: An updated systematic review and meta-analysis of randomized controlled trials. *BMC Surgery, 25*, 2805. https://doi.org/10.1186/s12893-025-02805-z

APPENDICES

Appendix 1: Interview Guides

1.1 Interview Guide: Portuguese Healthcare Professionals (Q1–Q22) draft version

Organisation and Adoption

Q1. Could you describe your hospital's current use of robotic-assisted surgery and which specialties it covers?

Q2. What motivated your institution to introduce or consider introducing robotic surgery?

Q3. What have been the main benefits and limitations observed so far?

Q4. What are the main barriers preventing wider adoption of robotic surgery in Portugal?

Q5. How were decisions regarding the acquisition or use of robotic systems made in your hospital?

Governance and Coordination

Q6. Is there a specific committee or governance body overseeing robotic surgery performance and training?

Q7. How do you ensure coordination between surgeons, nurses, biomedical engineers, and managers in robotic procedures?

Q8. What mechanisms exist to monitor outcomes, safety, or cost-effectiveness of robotic procedures?

Q9. How important is leadership and organisational culture for sustaining robotic surgery programs?

Ethics, Responsibility and Data Protection

Q10. How are ethical issues such as patient consent and data protection handled in robotic surgery?

Q11. Who is considered responsible in the event of a robotic malfunction or error: the surgeon, the hospital, or the manufacturer?

Q12. Are there formal ethical or legal frameworks guiding robotic surgery use in your institution?

Q13. Do robotic systems change the doctor–patient relationship or trust dynamics?

Q14. How is transparency ensured when AI or algorithmic support is involved in the surgical process?

Training, Workforce and Future Priorities

Q15. What kind of training or certification is required for staff to operate or assist in robotic surgery?

Q16. How are new team members integrated and trained in robotic procedures?

Q17. What are the main challenges your hospital faces regarding digital skills or workforce adaptation?

Q18. Do you feel there is sufficient institutional support for ongoing education in robotics?

Q19. What are the key priorities for improving robotic surgery implementation in Portugal?

Q20. How could national policies or funding mechanisms better support hospitals in adopting robotics?

Q21. What measures could strengthen transparency, ethics, and public trust in robotic surgery?

Q22. What lessons would you share with hospitals beginning their robotic surgery journey?

1.2 Interview Guide: Portuguese Healthcare Professionals (Q1–Q12)

Organisation and Adoption

Q1. How is the robotic surgery program currently organized in your hospital (active specialties, annual volume, number of robots)?

Q2. What motivated the introduction or expansion of the program, and what benefits and limitations have you observed so far?

Q3. What are the main barriers to expanding and optimizing robotic surgery in your institution (financing, staffing, operating room scheduling, maintenance)?

Financing and Utilization

Q4. How was the acquisition and operation financed (recovery funds, philanthropy, institutional budget, service contracts)?

Q5. How did you select the robotic platform and acquisition model? Are there performance SLAs?

Q6. How do you measure and manage utilization (cases, block scheduling, cancellations)?

Governance and Quality

Q7. What governance structure oversees training, credentialing and quality?

Q8. Which indicators do you monitor (safety, efficiency, cost-effectiveness) and how are they reported?

Q9. What role do leadership and organisational culture play in the sustainability of the robotic program?

Ethics and Future Priorities

Q10. How do you manage informed consent and data protection, including when AI-based support is involved?

Q11. When technical or clinically relevant incidents occur, what is the process for accountability and institutional learning?

Q12. What are the top three priorities for scaling robotic surgery with value (e.g., reimbursement, centralization, training, transparency)?

1.3 Interview Guide: International Healthcare Professionals (Q1–Q12)

Adoption and Implementation

Q1. How is robotic surgery organized and managed in your institution or country (e.g., specialties involved, case volume, integration timeline)?

Q2. What motivated its introduction or expansion, and what have been the main clinical or strategic outcomes so far? Probes: leadership commitment, organisational readiness, patient outcomes, workflow redesign.

Q3. What barriers or enablers have you observed in adopting or scaling robotic surgery (financial, cultural, regulatory, or training-related)?

Governance, Financing, and Utilization

Q4. How are investment decisions made (CAPEX, leasing, service contracts, public-private partnerships)?

Q5. What governance or oversight structures exist for credentialing, quality, and continuous improvement?

Q6. How is utilization measured and optimized (cases per robot, scheduling models, multi-specialty sharing)?

Quality, Data, and Learning

Q7. How is clinical performance monitored (metrics, dashboards, benchmarking)?

Q8. What processes ensure learning and feedback from complications or technical events?

Q9. How are training and competence maintained: locally or through manufacturer-led programs?

Ethics, AI, and Accountability

Q10. How are informed consent and patient transparency handled, particularly when AI, data sharing, or algorithmic decision support are involved? Q11. What ethical or governance frameworks guide responsible innovation in your institution? Q12. In your view, what lessons or recommendations from your experience could help other countries (such as Portugal) adopt robotic surgery safely and sustainably?

1.4 Interview guide: Industry Representatives (Q1–Q10)

Market Positioning, Adoption Drivers and Value Proposition Q1. Could you briefly describe your company's role and positioning in the robotic surgery market, and what you consider its main differentiating features compared to others? Q2. What are the main drivers motivating hospitals to adopt robotic surgery? **Economic Models, Accessibility, Implementation and Governance** Q3. How does your company approach the total cost of ownership (TCO) including purchase, maintenance, and instruments, and what financing models are most common? Q4. What measures are being taken to make robotic surgery more affordable and sustainable for smaller or public hospitals? Q5. How do you support hospitals during implementation and training, and how is performance monitored (dashboards, data analytics, follow-up)? Q6. How do you ensure quality assurance, credentialing, and ethical governance in partnership with hospitals? **Technology Evolution, AI Integration, Ethics and Future Recommendations** Q7. How is AI, data analytics, or digital assistance being integrated into your platform, and how do you view interoperability between different systems or data ecosystems? Q8. What are the ethical challenges in robotic surgery adoption, and how can they be mitigated? Q9. What do you see as the next major innovation or shift in robotic-assisted surgery over the next 5–10 years, technologically or economically? Q10.How can countries like Portugal learn from more mature systems to adopt robotic surgery ethically, sustainably, and efficiently?

Appendix 2: Interview Transcripts

2.1 Transcript PR1

Occupation: Urologist - Robotic Surgery (Professor, CMS & FMUL)

Institution: Hospital da Luz Lisboa

Q#	*Synthesized Response*

Q1.	The hospital performs mainly urologic robotic surgery, representing approximately 80 to 85 percent of all cases. Additional specialties include colorectal and hepatobiliary pancreatic surgery, thoracic surgery and gynaecologic oncology. The institution operates two Da Vinci systems. Surgical block time is assigned by specialty through fixed weekly schedules, supporting consistently high activity levels.
Q2.	Robotic surgery was expanded due to clear clinical advantages, particularly in prostate cancer. Benefits include reduced bleeding and pain, faster recovery, superior visualization and precision, and improved functional and oncologic outcomes. In renal surgery, robotics allows greater kidney preservation and shorter warm ischemia times. Limitations relate mainly to the initial investment cost and docking procedures rather than operative time.
Q3.	The main barrier is the acquisition and maintenance cost, estimated at 2 to 2.5 million euros plus annual service fees. However, a cost effectiveness study showed that improved clinical outcomes can generate financial savings within five years. Broader barriers include insufficient national planning and the installation of robotic systems in hospitals without the necessary case volume or trained teams.
Q4.	Most systems in Portugal are purchased directly. Other financing models include contracts based on consumables, PRR funding and philanthropy. Only one robotic system in the country was donated.
Q5.	The hospital uses the Da Vinci platform and expanded to two units due to high surgical demand. Specific performance agreements were not detailed, but emphasis is placed on stable maintenance and sustained high utilization.
Q6.	Operating room schedules are fixed by specialty and planned weekly. Despite occasional cancellations and insurance related delays, the hospital maintains an annual utilization rate close to 95 percent. Public hospitals typically achieve lower rates due to structural and staffing constraints.
Q7.	Urology follows a formal European training program with structured steps, proctoring and certification. In other settings, training may be limited to manufacturer sessions that teach system operation but not technical proficiency. The rapid national expansion of robotic surgery has not always been matched by structured training pathways, creating risks for program quality.
Q8.	Indicators include blood loss, operative time, intraoperative and perioperative complications, readmissions and length of stay. Procedure specific outcomes such as margin status, PSA control, continence and erectile function are also monitored. Functional domains are assessed using validated questionnaires.
Q9.	Leadership is essential. Lack of national coordination has resulted in robotic systems being placed in hospitals without sufficient case volume or trained personnel. High quality programs generally require at least 200 robotic procedures per year to maintain proficiency and financial viability.
Q10.	The hospital uses institution specific consent forms validated by the legal department. Current robotic systems function entirely as master slave platforms and do not involve autonomous decision making.
Q11.	Responsibility lies entirely with the surgeon, as robotic systems do not perform independent actions. Ethical issues related to autonomous systems do not currently apply to robotic surgery.
Q12.	Priorities include coordinated national planning, rational distribution of systems and alignment with real surgical volume. At the institutional level, essential components include structured training, proper certification, adequate case numbers and internal capacity building. There is concern that Portugal

	currently has more robotic systems than eligible patients, which may compromise long term program quality.

2.2 Transcript PR2

Occupation: Surgeon - Obesity & Metabolic Surgery (Coordinator)

Institution: Hospital da Luz Lisboa

Q#	*Synthesized Response*
Q1.	The hospital operates two Da Vinci systems. Robotic surgery is mainly performed by urology, followed by general surgery, thoracic surgery and gynaecology. Robotic procedures in colorectal cancer and bariatric surgery have grown steadily, and weekly block schedules are assigned to each specialty to manage access.
Q2.	The second robot was acquired due to rising demand and competition for operating time. Robotic surgery provides major advantages compared with laparoscopy, including 3D vision, enhanced precision and restoration of wrist-like movement that conventional instruments lack. Limitations include the absence of tactile feedback, which initially leads to suture breakage until surgeons adapt.
Q3.	The principal barrier is cost. Robotic procedures remain expensive for hospitals and for patients whose insurance does not authorize robotic use. Price limitations restrict access and slow the expansion of robotic surgery across different indications.
Q4.	The robotic systems were financed entirely by the private hospital group, including investment supported by philanthropy.
Q5.	Multiple platforms were tested by clinical teams. The hospital initially adopted the Intuitive platform and, after hands-on evaluations of new systems entering the market, chose to continue with the same platform based on performance and user familiarity.
Q6.	Weekly operating days are dedicated to each specialty, allowing predictable access. Utilization is monitored internally, with scheduling structured to accommodate case volume and team availability.
Q7.	The robotic program is led by a urology coordinator with a formal training pathway. General surgery has fewer cases and therefore relies on external training, with surgeons completing programs abroad before performing robotic procedures locally.
Q8.	Standard metrics include complications, bleeding, operative time and length of stay. Robotic surgery may increase operative time due to setup, but clinical outcomes are generally improved. Indicators are consistent with those used prior to robotic adoption, with incremental gains in precision and recovery.
Q9.	The program was driven primarily by clinicians, especially urologists, who advocated for investment based on clinical need and international adoption trends. The administration supported the initiative for strategic and technological positioning, leading to a combined medical and institutional motivation.
Q10.	The informed consent process mirrors that of conventional surgery but includes explanation of robotic-specific advantages, limitations and cost implications. When insurance does not authorize robotic procedures, patients choose between robotic and laparoscopic approaches after detailed counselling.

Q11.	Emergency protocols ensure safe undocking and conversion to laparoscopic or open surgery when needed. Mechanical failures are rare. Teams are trained to manage technical issues rapidly, maintaining patient safety throughout the procedure.
Q12.	Lowering costs is the most important factor for wider adoption. Increased platform competition is expected to reduce prices, similar to the evolution of laparoscopy. Continued clinical evidence demonstrating advantages across additional procedures is likely to support expansion.

2.3 Transcript PR3

Occupation: Nurse Manager - Operating Room (Deputy Role)

Institution: Hospital CUF Tejo Lisboa

Q#	***Synthesized Response***
Q1.	The interviewee coordinates an Iberian-level robotic surgery implementation program within the medical technology industry. The current role involves supporting hospitals during program rollout, training medical teams and facilitating the introduction of new robotic platforms across institutions.
Q2	Robotic surgery provides superior visualization, precision and access to deep or narrow anatomical structures. It allows preservation of nerves and vascularization that were difficult to protect in open surgery. Limitations are mainly related to learning curves and team resistance, similar to the early adoption of laparoscopy. However, after 15 years of robotic experience in Portugal, teams are increasingly trained and limitations have diminished.
Q3.	The main barrier is cost, which affects both public and private institutions. Despite high upfront investment, shorter recovery times and earlier return to work can generate long-term societal savings. Price reductions are expected as more platforms enter the market. Portugal currently has 26 robots, with projections showing 53 by the end of 2026.
Q4.	In private hospitals, investment is typically internal, justified by efficiency gains and patient outcomes. In public hospitals, expansion has depended primarily on PRR funding. Financing decisions differ because private institutions directly capture efficiency-related savings, while public institutions face budgeting constraints and slower decision processes.
Q5.	Platform selection is based on demonstrations and pilot use. Companies define training pathways and safety criteria. Clinical teams evaluate usability, capabilities and integration with surgical needs. Certification routes include technical training delivered by companies and clinical training completed in academic centres such as IRCAD and ORSI.
Q6.	Utilization varies across hospitals and depends on the number of trained clinicians and internal scheduling. Many hospitals allocate specific weekly days per specialty. Adoption rates increase once teams acquire technical proficiency and integrate robotic surgery into routine practice.
Q7.	Training follows a structured pathway beginning with basic skills training (similar to obtaining a driving license), followed by specialty-specific modules in areas such as prostate, kidney, colorectal or thoracic surgery. Companies ensure technical certification, while clinical certification is delivered in specialized European centres. This framework is designed to standardize safety and ensure competent use of robotic systems.

Q8.	Standard indicators include complications, operative time, blood loss and length of stay. Robotic surgery tends to increase setup time but improves precision and functional preservation, particularly in procedures such as prostatectomy. Functional outcomes benefit from magnified visualization that allows nerve-sparing techniques previously limited in open surgery.
Q9.	Leadership is essential in persuading administrations to prioritize robotic investment over other technologies. Decisions depend on the ability of clinical leaders to demonstrate long-term value. Sustainable programs rely on motivated teams, adequate case volume and institutional willingness to support the initial learning curve, which may temporarily increase operative times.
Q10.	Robotic surgery requires explicit patient consent stating that the procedure will be performed using a robotic system controlled by a surgeon. Patients must be informed of advantages, limitations and cost differences, particularly when insurance coverage varies.
Q11.	Robotic systems record all actions through internal logs, similar to a black box, allowing reconstruction of technical or human errors. When issues occur, audits examine maintenance history, system performance and case complexity. Mechanical failures are rare, but routine maintenance with certified parts is essential to ensure safety. Responsibility is evaluated based on combined review of system data, human actions and clinical context.
Q12.	Training is considered the central priority for sustainable expansion. Broader access to certification programs and increased availability of robotic systems are essential to support global growth projections. Without structured training and adequate equipment, widespread adoption cannot be achieved.

2.4 Transcript PR4

Occupation: Urologist - Robotic Surgery (Coordinator & Professor, Hospital de Santa Maria)

Institution: Hospital CUF Tejo Lisboa

Q#	***Synthesized Response***
Q1.	The hospital operates one Da Vinci Xi system, introduced in 2016. Robotic activity is mainly performed by urology, followed by general surgery, gynaecology and, less frequently, thoracic surgery. The robot is used daily, often at full capacity. Operating time is divided by specialty, with urology typically using the robot early in the week and general surgery later, occasionally extending into weekends.
Q2.	Robotic surgery is described as robot-assisted rather than autonomous, meaning all actions are executed by the surgeon through the console. Benefits include greater precision, tremor filtration, enhanced freedom of movement and a significantly shorter learning curve compared with laparoscopy. He highlights the IAG automation scale from 0 to 5, predicting that surgical autonomy may develop within the next 20 years. Limitations relate mainly to the current absence of automation, costs and the need for trained teams.
Q3.	Portugal currently uses three platforms: Da Vinci Xi, Hugo RAS and Versius, although Versius is rarely used. Expansion has been accelerated by PRR funding, often without adequate strategic planning. Several hospitals have acquired robots that are underused due to low case volume or lack of trained professionals. Barriers include insufficient surgeons, insufficient patient numbers in some regions and inconsistent national planning.

Q4.	Private hospitals initially led robotic adoption because the State lacked the capacity to finance systems costing 2 to 2.5 million euros. Public hospitals have recently acquired robots largely through PRR funding. Instrument costs remain high and contribute significantly to total program expense.
Q5.	The Da Vinci Xi was selected based on maturity and reliability. Historically, Intuitive held a near-monopoly after acquiring the competing Computer Motion platform. New competitors, including Medtronic and emerging Chinese manufacturers such as TUMAI, have recently entered the market, increasing platform diversity.
Q6.	Databases track length of stay, readmission rates, complications and recovery time. At CUF Tejo, postoperative recovery is faster and length of stay is consistently shorter in robotic cases. Operative times do not differ substantially from laparoscopy. Utilization is maximized through weekly specialty scheduling, with daily and often weekend use.
Q7.	Certification is required by all companies and includes theoretical modules, simulation training and animal-model practice. Clinical cases must initially be performed under the supervision of a proctor. European training centres such as ORSI (Belgium), IRCAD (France) and newer centres in Spain provide structured pathways. Certification is specialty-specific.
Q8.	Quality metrics include complication rates, operative time, blood loss and length of stay. Robotic surgery is associated with faster recovery, earlier discharge and higher surgical precision. Clinical outcomes guide team evaluation more than operative time.
Q9.	The respondent argues that Portugal lacks coherent national health policy and long-term planning. Many robots are purchased without matching surgical capacity. The respondent advocates centralizing robotic surgery in high-volume centres staffed by experienced teams, arguing that low-volume hospitals produce poorer outcomes. He also criticizes structural barriers such as professional orders and outdated regulations.
Q10.	Consent is identical to other surgical procedures but includes explicit information that the operation will use a robotic system. Patients increasingly request robotic surgery due to perceived benefits, often arriving already informed through online sources.
Q11.	Technical malfunctions are reported to the manufacturer. Surgeons with classical and laparoscopic training can convert procedures, when necessary, but he warns that newer generations may lack these foundational skills. He highlights the need for “rescue surgeons” in high-volume robotic centres to manage complications requiring conversion.
Q12.	The highest priority is concentrating robotic surgery in specialized centres with experienced teams and sufficient volume. The respondent proposes tele-surgery, enabled by low-latency networks, as a solution to distribute care without dispersing expertise. Broader reforms include revising professional regulations, addressing excessive bureaucratic barriers and aligning national policy with international innovation trends. The respondent argues that over-regulation limits innovation and predicts that autonomous systems and AI will evolve despite attempts to restrict them.

2.5 Transcript PR5

Occupation: Urologist - Robotic Surgery (EBU Examination Committee Member)

Institution: Hospital CUF Descobertas Lisboa

Q#	***Synthesized Response***
Q1.	Robotic surgery initially started in urology and later expanded to general surgery and gynaecology. Training involved joint teams of urologists and nurses, with certification conducted abroad in Belgium through Medtronic.
Q2.	Growth in Portugal was driven partly by patient demand and marketing, as many patients actively seek robotic procedures. A key limitation is that clinical benefit depends more on surgeon experience than on the technology itself. For well-trained laparoscopic surgeons, the difference is smaller, but robotics substantially improves surgeon ergonomics and comfort. In the public system, expansion was enabled mainly by European PRR funding.
Q3.	The main barrier is surgeon experience rather than the technology itself. Patient demand and marketing accelerate adoption, but inadequate training limits safe expansion. Low case volume in some institutions and the intensive operating room requirements of robotic surgery contribute to scheduling complexity.
Q4.	In the private sector, systems are purchased directly by the hospital group, sometimes linked to larger equipment deals. In the public system, procurement depends on two parallel tenders, one for consumables and one financed by PRR funds. Both processes have been delayed pending approval from national authorities.
Q5.	CUF Descobertas currently uses the Medtronic platform. His initial training was on the Da Vinci system, which he considers more advanced in instrumentation, experience and certification range, including thoracic surgery. Medtronic offers lower acquisition costs but has limitations in available instruments and certification for certain specialties.
Q6.	Operating days are allocated by team demand. The respondent's usual robotic day is Thursday, with overflow cases scheduled on Fridays due to surgical complexity and longer preparation times. Robotic cases require more anaesthetic planning, patient positioning and room setup compared with conventional laparoscopy.
Q7.	At CUF, Medtronic managed training and supported certification centres. Experienced surgeons can later certify newer colleagues after meeting minimum procedural requirements. Training is platform-led rather than unified nationally, and institutional structures for credentialing remain limited.
Q8.	There are no structured robotic-specific indicators in the public sector. Each specialty monitors outcomes based on standard oncology or functional metrics such as continence or renal preservation. Hospitals rely mainly on existing metrics rather than creating robotic-specific dashboards. In high-volume laparoscopic centres, differences between laparoscopy and robotics are moderate.
Q9.	Access to robotic surgery is a strong motivator for surgeons, influencing recruitment and retention. Sustainability depends on financing models, ease of access to the robot and institutional priority setting. Robotic surgery is perceived as strategically valuable for both public and private providers.
Q10.	Consent is similar to conventional surgery but explicitly states the use of a robotic platform. Patients often arrive already informed and prefer robotic surgery due to perceived advantages. Insurance approval influences final decision-making in some cases.

Q11.	The respondent reports one case involving port-site conflict that required assistance from the robotic technician. Recovery was difficult but completed. Institutional learning structures are limited; issues are often attributed to system constraints rather than formal review. He notes that robotic systems introduce shared responsibility between surgeon and manufacturer due to hardware and software involvement.
Q12.	In the public sector, sustainability requires centralizing cases in high-volume hospitals. Robotic platforms cannot be viably distributed across all institutions. In the private sector, viability depends on each group's financial model. He highlights tele-surgery as a potential disruptor, enabling expert surgeons abroad to operate remotely. Future expansion is likely to remain concentrated in selected centres.

2.6 Transcript PR6

Occupation: Nurse - Operating Room (Health Consulting)

Institution: Hospital De Santa Maria Porto

Q#	*Synthesized Response*
Q1.	The hospital has one orthopaedic robotic system (Stryker Mako), acquired for approximately one million euros. It is used exclusively in orthopaedics, particularly for knee arthroplasty (90 to 95 percent of cases), with some hip arthroplasty. Annual robotic volume is around 90 to 100 procedures. The interviewee works as a senior robotic instrumentation nurse and supports two private surgical teams.
Q2.	Robotic surgery was introduced in orthopaedics due to global evidence demonstrating improved precision, reproducibility and predictability. Over 2 million procedures worldwide and more than 500 published studies support gains in accuracy, bone-cut precision and postoperative stability. Benefits include sub-millimetric accuracy and improved alignment. Limitations include high acquisition cost, dependence on proprietary implant systems and the influence of industry marketing on adoption.
Q3.	Key barriers include cost, learning curve and resistance from clinicians using competing systems. Robotic orthopaedic systems require adaptation: around 5 procedures for nursing teams and 20 to 30 for surgeons to achieve confidence and efficiency. Initial operative times can be 20 to 40 percent longer. Some professionals expect immediate statistical superiority, creating scepticism.
Q4.	The system was purchased directly by the private hospital. In the public sector, expansion depends on PRR funding and central tenders. He notes that the 2026 State Budget included investment in robotic surgery, but implementation has been slow and politically complex.
Q5.	The Stryker system was selected due to global market leadership in orthopaedic robotics. Four orthopaedic platforms currently exist in Portugal: Stryker Mako, CORI (Smith & Nephew), ROSA (Zimmer Biomet) and the upcoming VELYS (Johnson & Johnson). Each has specific certification pathways. The Stryker platform requires the use of Stryker implants, generating revenue through implant sales and procedural consumables.
Q6.	Around 90 to 100 cases are performed annually. Knee arthroplasty accounts for most procedures. Additional surgical indications such as unicompartmental knee or spine surgery can be added through software upgrades costing around 100,000 euros per module. Surgical days are allocated based on team scheduling.

Q7.	Training varies by company. Surgeons undergo formal certification in international centres, while nurses receive in-hospital training from product specialists. Teams must include two surgeons and three nurses (anaesthesiology, circulating and instrument nurse). The product specialist must be present throughout the entire procedure and holds system access credentials.
Q8.	Benefits include high reproducibility, precision under one degree of deviation and prevention of soft tissue injury due to built-in safety margins. Operative time initially increases but approaches conventional times after proficiency. Patient outcomes appear to include reduced postoperative pain and earlier discharge, although global statistics remain mixed for orthopaedic robotics at this stage.
Q9.	Leadership is essential in managing expectations. The robotic paradigm is not to operate faster but to operate better and reduce revision surgeries over the next 20 to 30 years. Robotic surgery slows immediate throughput but may reduce the lifetime need for reoperations, which should be considered in institutional planning. Management pressure for rapid results conflicts with the long-term nature of orthopaedic robotic benefits.
Q10.	Consent mirrors conventional surgery but includes explicit communication that a robotic system will be used. Systems are fully certified by FDA, EMA and INFARMED Data are transmitted to the USA and stored by manufacturers, raising questions for future machine-learning–based decision support. Robotics is currently surgeon-controlled; autonomous functions remain limited due to safety and regulatory constraints.
Q11.	No robotic system failures have occurred locally. Product specialists must remain present throughout the procedure and hold the system password. If problems arise, the team can convert to manual surgery. Future questions remain about responsibility sharing between surgeons, hospitals and companies as platforms accumulate data and evolve toward greater autonomy.
Q12.	Priorities include cost reduction through market expansion, development of national training centres and increased platform autonomy. Future evolution will incorporate augmented and virtual reality and integrated imaging. In the long term, robotics will shift from implant-based surgery to regenerative solutions using nanorobots and biological reconstruction, reducing the need for prosthetic implants and revision surgeries.

2.7 Transcript PS1

Occupation: Surgeon - Hepatobiliary & Robotic Surgery

Institution: Hospital Curry Cabral

Q#	*Synthesized Response*
Q1.	The hospital received its first Da Vinci robot in 2019 through a donation and a second one in 2021 or 2022. It currently operates two Da Vinci platforms (one Xi and one X), both in continuous use. Robotic surgery initially began with urology and hepatobiliary surgery and later expanded to colorectal, bariatric, esophagogastric, thoracic, gynaecology and paediatric surgery. The respondent explains that distributing operating time across too many specialties at the start, with access only every 15 days, significantly slowed the learning curve. Concentrating initial activity in fewer teams accelerated progress and supported program maturity.

Q2.	Robotic surgery entered the public sector later than the private sector, and its introduction at this hospital was driven by the need to align with international standards and expand access to minimally invasive care. Benefits include smaller incisions, faster recovery, reduced pain, earlier ambulation, shorter hospital stay and quicker return to daily activities. Compared with laparoscopy, robotics provides superior instrument articulation, enhanced precision and improved nerve-sparing capability, enabling complex procedures that were previously difficult or impossible laparoscopically. Limitations relate mainly to cost and the need for structured planning and sustained training.
Q3.	The respondent identifies cost as the main barrier, but stresses that the real challenge lies in systemic inefficiencies unrelated to robotics, such as prolonged admissions due to limited access to procedures like ERCP. A critical barrier is the lack of institutional support for training. Clinicians must frequently self-fund international training, cover accommodation and travel, and compensate with additional work upon returning. These constraints delay progress and create personal and financial strain.
Q4.	The first robot was donated, enabling the program to begin. The second robot was acquired as demand increased and capacity was insufficient for one platform alone. Robotic procedures run daily and often extend into weekends, particularly for transplantation cases, indicating sustained need for two systems.
Q5.	Two Da Vinci platforms operate in the hospital. Platform decisions were influenced by reliability, clinical need and available models. The respondent emphasizes that simply obtaining a robot is not enough; success requires coordinated planning across specialties and structured, continuous training.
Q6.	Utilization is arranged through weekly specialty-based scheduling. As more specialties adopted robotics and a second robot became available, operating slots were redistributed. Services frequently exchange allocated days to maintain continuity of care. Both robotic platforms consistently run at full capacity.
Q7.	Intuitive provides initial machine-specific training through theoretical instruction, simulation and local supervision. Certification through centres such as IRCAD or ORSI ensures technical competence but does not replace specialty-specific surgical training. Advanced development depends heavily on pre-existing minimally invasive experience and external observerships. The respondent highlights that, in the public system, training is largely self-funded and structurally unsupported, creating significant barriers for clinicians.
Q8.	The hospital monitors general surgical indicators such as morbidity and mortality reviews, length of stay and postoperative outcomes across open, laparoscopic and robotic procedures. Prospective multicentre research in hepatobiliary surgery is ongoing to compare robotic, laparoscopic and open outcomes, although comparisons with laparoscopy are biased due to differences in case complexity.
Q9.	Leadership is essential for ensuring structured and strategically phased implementation. The respondent notes that attempting to distribute robotic access evenly across many teams for political fairness harms program growth. Sustainable development requires focusing initial training on a small number of committed teams, who can later help expand the program. Institutional culture must shift to better support training and reduce the personal burden placed on clinicians.
Q10.	Consent follows the same format as other procedures but specifies the use of a robotic system. The robot operates entirely under surgeon control. Patients receive full information on risks, benefits and alternatives before consenting.

Q11.	Teams are trained to manage recoverable and non-recoverable errors. Technical failures are rare due to strict maintenance protocols and instrument life-tracking. If needed, teams convert to open surgery. Manufacturer representatives can support troubleshooting remotely. The respondent highlights that robotic systems provide greater equipment safety than some conventional laparoscopic environments, where instrument quality control is inconsistent.
Q12.	The respondent highlights two priorities: structured implementation and investment in training. Hospitals should avoid dividing robotic access across too many teams with minimal operating time. Instead, a smaller number of teams should train intensively to build program capacity. National planning should identify which hospitals are suited for high-volume complex robotic surgery, while others should focus on less complex procedures. Broader reforms are needed in the public system to support clinician training and reduce systemic inefficiencies.

2.8 Transcript PS2

Occupation: Surgeon - Obesity & Metabolic Surgery (Robotic Surgery Unit)

Institution: Hospital Curry Cabral

Q#	***Synthesized Response***
Q1.	The hospital received its first Da Vinci robot in 2019 through a donation from the Ismaili Imamat Foundation (AKH) and now operates two Da Vinci systems. It was the first public hospital in Portugal with robotic capability. Robotic surgery is used across general surgery (including thyroid, esophagogastric, bariatric, hepatobiliary, pancreatic and colorectal procedures), as well as urology, thoracic surgery, paediatric surgery and gynaecology. Weekly OR allocation is specialty-specific. The respondent performs bariatric robotic surgery typically on Wednesdays with full-day access to the robot.
Q2.	National adoption accelerated over the last 3 to 4 years due to evident benefits: increased precision, better visualization, ergonomics and enhanced safety. Robotics is seen as a natural evolution of MIS. The respondent highlights major patient benefits and surgeon comfort. Concerns traditionally relate to cost and operative time; however, once the learning curve is overcome, operative times become similar to laparoscopy. Costs are expected to drop as new platforms from Asia enter the European market.
Q3.	Cost remains a central barrier, particularly due to limited budgets and consumable expenses. Training access is another barrier: many clinicians must self-fund international certification and compensate by increasing clinical workload later. Growing demand requires better planning for high-complexity cases, such as bariatric patients with 200–250 kg, who clearly benefit from robotics but cannot yet be systematically prioritized due to scheduling constraints.
Q4.	The first robot was donated. The second system was installed through a consumables-based model, in which high instrument volume triggered provision of an additional platform at no direct acquisition cost. Instrument use is limited to 15–18 cycles, creating predictable replacement demand. Maintenance and training also add to long-term program costs.
Q5.	The hospital operates Da Vinci systems, historically the dominant platform since 1999 due to long-standing patents. As patents expire, manufacturers from China, Japan, Korea and India are entering the

	market, reducing acquisition and consumables costs. Choice of platform is linked to reliability, training pathways and strong global clinical experience.
Q6.	Utilization is managed through weekly specialty-based scheduling. The two robots operate continuously, with one allocated to bariatric surgery and the other to colorectal or other specialties. In high-demand moments, robots run on weekends, especially for transplant cases. Instrument consumption and maintenance cycles indirectly reflect utilization intensity.
Q7.	Currently, training and credentialing remain under the responsibility of platform manufacturers. The respondent trained at IRCAD Strasbourg with costs fully covered by the company. Professional societies, such as TROGS (The Global Robotic Surgical Society), advocate for transitioning training oversight to scientific societies rather than companies, ensuring certification independent of platform. Training focuses on mastering robotic controls within each surgeon's specialty.
Q8.	Standard quality indicators are used, including complication rates, conversion to laparoscopy, operative time, length of stay and functional outcomes. Robotics is considered an extension of laparoscopic surgery, improving precision and safety. Some outcomes from the United States demonstrate that insurers no longer reimburse prostatectomies unless robotic, due to reduced incontinence and erectile dysfunction risk.
Q9.	Robotic programs strengthen surgeon motivation and retention, particularly within the SNS. Access to robotic technology helps keep skilled clinicians in the public sector despite financial pressures. Clinicians value the opportunity to perform high-complexity procedures with enhanced safety. Sustaining programs requires supportive leadership and long-term commitment from government to maintain technological investment.
Q10.	Informed consent does not yet specify robotic surgery, which the respondent believes should be improved. Due to long waiting times, patients are listed years before knowing whether surgery will be robotic or laparoscopic. Most patients welcome robotic surgery once clarified that the robot is not autonomous. One fully autonomous cholecystectomy has been performed in an animal model, but this is not yet clinically available.
Q11.	Technical malfunctions occasionally occur, such as robotic arms stopping or instrument failures, requiring conversion to laparoscopy. Since surgical robots are not autonomous, responsibility remains with the surgical team. The respondent acknowledges that future autonomous systems will raise complex ethical and legal questions regarding responsibility, involving surgeons, hospitals and manufacturers.
Q12.	Priorities include continuing national investment, ensuring structured and equitable access to robots in public hospitals and strengthening clinician motivation to remain in the SNS. Cost differences between sectors influence access; in private hospitals, robotic surgery adds 3,000 to 4,000 euros per procedure, limiting use. The respondent believes that sustained investment in robotics motivates professionals, supports training of younger surgeons and contributes to retaining talent within the public sector.

2.9 Transcript PS3

Occupation: Surgeon - Abdominal Wall & Robotic Surgery (Unit Head)

Institution: Hospital Garcia de Orta

Q#	*Synthesized Response*
Q1.	The hospital operates a single Da Vinci system. Robotic surgery is performed in four specialties: general surgery, urology, gynaecology and otolaryngology. The robot is available daily, with one operating room session assigned each day to one of the four specialties based on a rotating schedule.
Q2.	The program was implemented to align with advances in MIS and to address the limitations of conventional laparoscopy in anatomically confined or technically demanding cases. Robotics enhances precision, reduces surgical trauma and blood loss and enables standardized execution of complex gestures, particularly in pelvic surgery and complex ventral hernia repair. Reported benefits include shorter length of stay, reduced postoperative pain, lower morbidity and decreased direct and indirect treatment costs.
Q3.	The main barrier is insufficient operating room time caused by a shortage of anaesthesiology staff. Limited human resources restrict the ability to schedule additional robotic sessions and prevent the robot from reaching full operative potential.
Q4.	The robotic platform was acquired through PRR funding.
Q5.	The system was selected through a competitive tender process. Platform choice followed public procurement procedures, ensuring compliance with legal and financial requirements.
Q6.	Utilization is monitored through annual surgical productivity reports. Efficiency and case volume are assessed using internally tracked surgical activity and distribution of block time across specialties.
Q7.	Training and certification are provided by the entity responsible for the robotic program, with support from the platform manufacturer. This includes structured modules delivered by Intuitive, ensuring standardized technical training for all team members.
Q8.	The hospital monitors postoperative outcomes such as overall morbidity, average length of stay and readmission rates. These indicators are used to evaluate quality and guide continuous improvement across robotic procedures.
Q9.	Departmental leadership plays a key role in supporting and sustaining robotic surgery by ensuring organisational alignment, facilitating training and coordinating operating room access. Strong service-level commitment has supported continued program stability.
Q10.	Informed consent is completed digitally and stored in the patient's confidential clinical record. The process follows institutional standards for data protection and documentation.
Q11.	Any technical or clinically relevant incident is formally reported and communicated to the surgical department, operating room management and the platform manufacturer. This ensures traceability, corrective action and institutional learning.
Q12.	The main priorities include investing in additional anaesthesiology staff, implementing structured multidisciplinary training and conducting regular annual audits. Strengthening human resources and systematic evaluation is considered essential for scaling capacity and improving program value.

2.10 Transcript PS4

Occupation: Surgeon - Colorectal, Oncology, MIS & Robotics

Institution: Hospital Garcia de Orta

Q#	***Synthesized Response***
Q1.	The respondent works in a hospital with two Da Vinci robots. The program began in 2019, initially led by general surgery rather than urology. Current active specialties include general surgery, urology, thoracic surgery and gynaecology. Within general surgery, colorectal and hepatobiliary pancreatic procedures represent major areas of robotic activity.
Q2.	In colorectal surgery, especially rectal cancer, robotics provides clear advantages: enhanced precision, tremor reduction, smaller and more flexible instruments and superior access in narrow pelvic spaces. This leads to better oncologic outcomes, including improved long-term control. Other specialties, such as hepatobiliary surgery, are beginning to document similar benefits. Limitations are primarily logistical and economic, as robotic capacity is limited by the availability of operating rooms and the high cost of equipment.
Q3.	The main barrier is limited operating room availability and economic constraints. Although clinical teams would welcome broader access, it is not feasible to place a robot in every OR. Expansion depends on hospital resources and the ability to support consumable costs and instrument turnover.
Q4.	The first robot was acquired through a mixed model combining private foundation support and public funding. Ongoing costs are covered by the hospital, with financing based on consumables use. The respondent explains that consumables correspond mainly to robotic instruments.
Q5.	The Da Vinci system was selected because it was the only mature and clinically validated platform available in 2019. The choice resulted from an agreement between the supporting foundation and hospital leadership. At the time, no other approved robotic platforms offered comparable clinical reliability.
Q6.	Utilization follows weekly specialty-based allocation. Specialties with national reference centres, such as urology, colorectal cancer and hepatobiliary pancreatic surgery, receive greater access to the robot. Each specialty is guaranteed at least one or two operative sessions per week, with flexibility to exchange days as needed.
Q7.	A robotic surgery committee led by a urologist oversees the program. Training and credentialing are still controlled by Intuitive. Surgeons are nominated by service directors, complete basic and advanced modules (TR 100, TR 200, TR 300) and often train abroad. The respondent notes that platform training focuses on system use; surgeons must already be competent in MIS to perform robotic procedures safely.
Q8.	The program monitors survival and disease-free survival for oncology cases, as well as operative time, conversion rates, complications and length of stay. International benchmarks, such as those recently published for robotic liver surgery, guide comparison. The service conducts regular clinical meetings, including semi-annual performance reviews.
Q9.	Leadership is essential for securing funding, supporting training and motivating teams. Economic sustainability is challenging because robotic surgery is more expensive per case, but broader societal benefits such as earlier return to daily activity and reduced morbidity justify investment. Sustained progress requires motivated teams and continued administrative support.
Q10.	Consent is obtained for MIS in general, covering both laparoscopic and robotic approaches. The respondent explains that only one weekly robotic session is available, so procedures cannot be

	guaranteed as robotic for every patient. Teams explain the possibility of robotic use and match patients to the modality that provides the greatest clinical benefit. Rectal cancer in obese male patients, for example, benefits significantly from robotic access.
Q11.	Responsibility depends on whether an issue is caused by the system or by operative technique. The respondent uses an analogy: operating a robot is similar to driving a high-performance car; misuse reflects operator learning, not manufacturer failure. Any technical issue is reported to the manufacturer, who provides remote or on-site support. If an instrument malfunction risks patient harm, the team converts immediately. All incidents are reviewed in daily clinical meetings to support institutional learning.
Q12.	Priorities include reducing system costs and expanding access to more patients. The respondent foresees the emergence of more affordable competing platforms in the near future. Ideally, all eligible patients would undergo robotic surgery, but economic constraints still limit access. He expects future growth to come from technological diversification and improved affordability.

2.11 Transcript PS5

Occupation: Assistant Doctor - Urology (Senior/Consultant Level)

Institution: Hospital Professor Fernando Fonseca

Q#	***Synthesized Response***
Q1.	The hospital operates one Da Vinci Xi robot. For the first eighteen months, robotic activity was performed exclusively by urology. General surgery has recently begun to adopt the platform. The respondent works as a senior urologist with extensive robotic experience across public and private institutions.
Q2.	Adoption was motivated by clearly superior clinical outcomes for complex laparoscopic procedures, especially prostate and kidney cancer surgery. Benefits include significantly reduced blood loss, lower morbidity, shorter recovery and improved functional outcomes such as continence and erectile preservation. In renal surgery, robotics enables removal of tumours located in anatomically challenging positions with greater safety. Limitations include very high acquisition and consumable costs. Instrument lifespan constraints increase expenditure, making robotic surgery considerably more expensive per case despite strong clinical benefit.
Q3.	The respondent emphasizes that robotic systems are financially demanding and that both public and private sectors face structural limitations. The public sector faces cultural and operational challenges, including prolonged sick leave periods that diminish societal productivity gains, and limited planning capacity. A broader systemic issue is the lack of accountability and insufficient alignment between training needs and institutional support.
Q4.	The robot was acquired through PRR funding. The respondent notes that most public hospitals relied on PRR to obtain robots, as prior national investment in robotic systems was limited.
Q5.	The hospital operates a Da Vinci Xi system. The respondent previously implemented robotic programs in multiple private hospitals and completed formal certification abroad. Platform choice reflects the dominant position and clinical maturity of the Da Vinci system.

Q6.	Weekly operating room allocation includes two days for urology and two for general surgery. A fifth day is reserved for other specialties, though interest has been limited. Variability in demand and differing levels of team readiness influence effective weekly utilization.
Q7.	Training requirements include basic platform certification, international modules and supervised cases with a proctor. The respondent highlights that training is expensive, often self-funded, and insufficiently supported in the public sector. Experienced surgeons frequently proctor junior colleagues without compensation, transferring expertise from the private to the public sector. This creates structural tensions: senior clinicians bear responsibility and risk without institutional incentives, while newer generations may have fewer opportunities to develop foundational open and laparoscopic skills.
Q8.	Robotic-specific dashboards are not extensively developed. Quality is monitored through standard surgical and oncological outcomes. The respondent notes that clinical advantages of robotics in functional and oncological domains are well established in prostate and kidney cancer surgery.
Q9.	The respondent describes significant structural instability in hospital leadership, including recent mass resignations in administration and clinical direction. High patient volume and resource scarcity create unsustainable pressure on services. Robotic surgery exposes deeper systemic challenges: workforce shortages, generational differences in training expectations, lack of incentives for teaching and pressure from managerial models focused on short-term metrics rather than long-term program development.
Q10.	Informed consent does not differ from conventional MIS. Decision-making about robotic versus laparoscopic approach is service-based. The respondent notes that teams generally know in advance which patients will undergo robotic surgery.
Q11.	The respondent reports one technical malfunction in approximately 500 cases, which was managed safely by pausing and restarting the system. Strong experience in open and laparoscopic surgery allows conversion when needed. However, the respondent expresses concern that newer generations may lack foundational surgical skills to manage rare but critical complications, raising future questions about readiness and patient safety.
Q12.	Priorities include ensuring equitable patient access to robotic surgery in the public sector, increasing the number of robotic systems in hospitals capable of high-volume programs, and improving training infrastructure. The respondent strongly criticizes the deployment of robots in hospitals without MIS programs, calling it a misallocation of resources. Sustainable expansion requires coordinated national planning, recognition of training as a long-term investment, and alignment between clinical capacity, institutional readiness and robotic allocation.

2.12 Transcript PS6

Occupation: Urologist - Prostate Cancer, BPH & Andrology

Institution: Hospital Universitário de São João Porto

Q#	***Synthesized Response***
Q1.	The hospital currently operates one Da Vinci robot, with a second unit expected to arrive in November. Robotic activity is concentrated in urology, general surgery and gynaecology, which account for nearly all procedures. A formal coordination structure is limited; although a committee exists, practical

	management is overseen by the clinical direction and operating room administration. The urology service performs approximately 150 robotic prostatectomies per year, functioning as a high-volume centre.
Q2.	Benefits are most evident in functional outcomes for prostate cancer surgery, including lower rates of erectile dysfunction and urinary incontinence, along with faster recovery and discharge within 24 hours. Operative time initially increased during the learning phase but has since returned to baseline and recently improved, allowing three to four cases per day. Limitations include early learning-curve inefficiency and varying benefits across specialties.
Q3.	The primary barrier is cost. Although many public hospitals obtained robots through PRR funding, ongoing expenses remain substantial, including maintenance contracts and consumables with high per-case cost. The respondent considers the national expansion somewhat illusory, as installation has outpaced planning and long-term sustainability.
Q4.	The hospital purchased its first Da Vinci through internal budget allocation. The second unit was obtained through PRR funding. Consumables and maintenance remain recurring institutional expenses.
Q5.	Both robotic systems are Da Vinci units. Platform selection was influenced by availability and established market dominance.
Q6.	Operating time allocation is rigidly divided between specialties at the start of each year, not based on waiting list length or real-time clinical need. The structure is fixed in hours rather than case volume. Despite scheduling constraints, the respondent reports no underutilization; teams attempt to use available time as fully as possible.
Q7.	Training provided by the manufacturer is described as minimal, focusing mainly on meeting legal requirements for safe machine handling, including emergency shutdown procedures. The respondent states that this is not substantive technical training in robotic surgery. Clinical training occurs informally through mentorship by more experienced colleagues. Training intensity differs by company: Da Vinci offers very short training (one morning to one day), while Medtronic provides more comprehensive programs lasting approximately one week.
Q8.	There is no standardized or continuous robotic-specific monitoring system. Outcomes are reviewed retrospectively when the service chooses to do so, typically at year's end. There is no formal protocol or dashboard for ongoing evaluation.
Q9.	The respondent perceives limited strategic leadership focused on value creation. The priority appears to be demonstrating that the hospital possesses robotic capability rather than ensuring efficient, cost-effective use or maximizing patient benefit. Broader institutional motivation or long-term strategic planning is described as limited.
Q10.	Consent is the same as for other minimally invasive procedures. The Da Vinci system does not automatically store surgical images; however, instrument movements may be logged. In contrast, the Medtronic system records images to anonymized cloud databases. Data protection therefore varies by platform, but the respondent reports no major concerns under current practice.
Q11.	Emergency management is part of the initial technical training. Teams learn how to deactivate the robot or convert to open surgery if system failure occurs. The respondent emphasizes that this is one of the few substantive elements of the initial manufacturer-led training.

Q12.	Three priorities are identified: (1) national centralization of high-volume procedures rather than distributing robots broadly across hospitals; (2) assessing which procedures provide real added value when performed robotically, given limited resources; and (3) ensuring adequate training rather than following technological trends without strategic planning.

2.13 Transcript IHP1

Occupation: Urologist - Robotics, Prostate Cancer & Salvage Therapies (Senior)

Institution: Perituskliniken

Q#	***Synthesized Response***
Q1.	Robotic surgery has been used in Sweden for almost twenty years and is fully integrated in routine care. Multiple specialties use robotics, although prostate cancer surgery represents nearly all prostatectomies performed in the country. The respondent works in a high-volume private clinic after many years in a university hospital. Adoption expanded across nearly all regions.
Q2.	Adoption was driven by reduced blood loss, shorter recovery, fewer complications, better ergonomics and patient demand. Early Swedish studies showed that functional outcomes depend heavily on surgeon proficiency, although robotics enhances precision and consistency. Leadership support and national modernization efforts also influenced expansion.
Q3.	Political support, experienced early adopters and strong regional investment enabled growth. Barriers included initially high costs and creation of many low-volume centres, which the respondent believes reduces quality and limits safe learning. Training standards also differed across hospitals.
Q4.	Robots were acquired primarily through direct public investment by regional authorities. Financing relied on capital investment rather than leasing. Costs became more acceptable once adoption spread across the system.
Q5.	Sweden does not have a national accreditation system and each hospital defines its own criteria. The respondent compares this with Denmark, where only a small number of accredited centres are allowed to perform robotic prostatectomy. The respondent believes Sweden should have followed a centralized accreditation model to safeguard quality.
Q6.	Utilization is monitored internally and through national reporting. High-volume centres perform several hundred cases each year, whereas smaller hospitals struggle to maintain adequate caseloads. The respondent considers centralization essential to ensure proficiency.
Q7.	Sweden maintains the National Prostate Cancer Register, one of the most comprehensive outcome registries in the world. It monitors complications, blood loss, margin status, continence, erectile function and patient-reported metrics. Surgeons can benchmark their results against national averages, and hospital-level results are publicly available.
Q8.	Robotic systems record detailed technical information that helps analyse complications or system issues. Intuitive provides remote monitoring and rapid technical guidance. The respondent reports that system failures are rare but all complications are reviewed locally and compared with national trends.
Q9.	Training quality varies. The respondent explains that a surgeon requires roughly two hundred cases to become comfortable and may reach the highest proficiency after nearly one thousand cases. Many

	hospitals cannot deliver this volume. Manufacturer courses support learning but cannot replace sustained experience.
Q10.	Informed consent includes explanation of robotic benefits and limitations. Robots remain entirely surgeon-controlled. Technical data are shared under Swedish regulatory rules, and patients accept this due to strong national transparency frameworks.
Q11.	Ethical concerns include excessive dispersion of robots, low-volume practice and use of robotics for procedures that do not clearly benefit from the technology. The respondent recommends prioritizing robotics for prostate, kidney, bladder and rectal cancer.
Q12.	Recommendations include: (1) centralizing robotic surgery in high-volume accredited centres; (2) restricting acquisition to hospitals with sufficient surgical volume; (3) limiting the number of surgeons per robot; (4) establishing national outcome registries; (5) creating transparent reporting of surgeon- and hospital-level results; (6) implementing national, not hospital-based, credentialing; and (7) regulating acquisition to prevent low-value use of robotics.

2.14 Transcript IHP2

Occupation: Operating Room Nurse - General Surgery (Registered Nurse)

Institution: Linköping university Hospital

Q #	***Synthesized Response***
Q1.	The hospital operates two robotic systems shared by urology, colorectal, gynaecology and upper GI surgery. Each specialty manages its own schedule, resulting in a structured weekly distribution of operating time. Robotics has been integrated for over a decade and is now a routine part of surgical care, especially in urology and gynaecology, where case volumes are highest.
Q2.	Robotic surgery was introduced to improve surgical precision, reduce recovery time and enhance postoperative outcomes. Early adoption by urology paved the way for other specialties. Leadership engagement and surgeon motivation were central drivers. Clinically, the hospital has observed shorter stays, fewer complications in selected procedures and high patient satisfaction. Strategically, robotics has strengthened the institution's reputation as a leading centre for advanced surgical care.
Q3.	Enablers included supportive leadership, experienced colleagues who mentored new team members and substantial training support from the robotic company. Financial and cultural barriers were less pronounced because robotics was already well established when the respondent joined. Training opportunities provided through vendor collaboration accelerated the respondent's integration into the program.
Q4.	Robotic system purchases follow a structured CAPEX pathway. Proposals begin at the departmental level, supported by outcome data and efficiency projections, then proceed to hospital leadership and the regional health authority for funding approval. Both systems are hospital-owned and covered by comprehensive service contracts. Decisions around upgrades and training packages are coordinated with the vendor to ensure safety, reliability and cost-effectiveness.

Q5.	Credentialing, quality oversight and continuous improvement are overseen through internal governance structures, though specifics were not detailed in the interview. Multidisciplinary discussions and adherence to established protocols guide safe implementation and ongoing quality assurance.
Q6.	Utilization is optimized through multispecialty scheduling and coordination across services. Complex patients requiring interventions from different specialties may be scheduled for combined procedures during a single admission to increase efficiency. Ongoing work focuses on standardized workflows to increase daily throughput and enable an additional patient per day when feasible.
Q7.	Surgeon's log into the robotic system with personal credentials, allowing objective tracking of metrics such as case number, console time and procedure-specific performance. Data is also submitted to national quality registries. These mechanisms support benchmarking, personal development and institutional quality monitoring.
Q8.	All intraoperative complications, unexpected events and system-related issues are documented immediately. These are reviewed during structured morbidity and mortality meetings, allowing multidisciplinary reflection on root causes and improvement opportunities. Lessons learned feed into revised protocols, checklists and workflows.
Q9.	Surgeons receive extensive manufacturer-led training including simulation and structured progression until full procedural competence is reached. Nurses focus on system operation and workflow, which becomes increasingly standardized over time. Emergency simulations (e.g., undocking) become less frequent as teams mature, but standardized protocols maintain readiness and safety.
Q10.	Consent includes explanation of robotic use, risks and alternatives. Data are handled under national privacy rules. In blinded trials, patients receive appropriate study information.
Q11.	Ethical governance is guided by national authorities, including the Swedish Ethical Review Authority, the National Board of Health and Welfare and the Swedish Medicines Agency. Internally, multidisciplinary governance ensures that new techniques undergo evidence review, risk assessment and appropriate training before implementation. Close collaboration with the university ensures compliance with Good Clinical Practice for all research. A culture of transparency and communication reinforces responsible innovation.
Q12.	Key recommendations include developing small, highly proficient teams; adhering strictly to established protocols; and learning from high-volume centres internationally. The respondent emphasizes the importance of visiting leading institutions, adopting proven best practices and fostering an environment that supports continuous learning and collaboration for sustainable robotic surgery adoption.

2.15 Transcript IR1

Occupation: Specialist - Robotic Surgery Start-Up Development

Institution: Medtronic

Q#	***Synthesized Response***
Q1.	The respondent works as a Start-Up Specialist for the Medtronic HUGO RAS platform. The system differentiates itself through an open-console design that maintains communication with the operating

	room team. It also includes four independent robotic arms that provide wide anatomical reach and flexibility. Medtronic positions itself as a major global competitor that challenges the long-standing dominance of a single company.
Q2.	Hospitals adopt robotic surgery because global practice is shifting from laparoscopy to robotic-assisted surgery. This transition is driven by technological evolution, surgeon comfort and patient expectations. Robotics enhances ergonomics, reduces fatigue, supports complex procedures and contributes to improved clinical outcomes. It also strengthens institutional reputation, creates clinical differentiation and contributes to faster recovery for patients.
Q3.	Total cost of ownership varies with utilization. The more frequently a robot is used, the lower the cost per intervention. Costs include acquisition, instruments, sterilization, logistics and maintenance contracts. Adoption in Portugal is increasing because of European recovery funds. Competition in the market is reducing prices after more than two decades of limited alternatives. Medtronic promotes transparent cost structures and extensive implementation support to optimize economic efficiency.
Q4.	Accessibility increases through market diversification, as hospitals now have more than one platform available. Several new manufacturers are entering the sector, and some systems replicate earlier architectures at lower operational cost. For smaller or public hospitals, European funding and Medtronic's modular design help reduce barriers. Greater competition promotes affordability and long-term sustainability.
Q5.	Medtronic uses a multi-stage implementation pathway. Teams receive simulation training, online modules and several days of hands-on training in accredited international centres. After certification, Medtronic provides support during the initial clinical cases and assists with workflow design, logistics and stock management. Continuous accompaniment ensures safe integration and promotes stable team performance.
Q6.	Quality assurance is achieved through structured multi-step certification that is more rigorous than one-day certification models offered by some companies. Portugal does not have a national credentialing system, so standards vary across vendors. Medtronic enforces detailed preparation and supervised early operations. Ethical governance includes managing expectations, ensuring readiness of teams and promoting safe adoption.
Q7.	The respondent expects artificial intelligence to become a key component of future robotic systems. Anticipated developments include real-time identification of structures, predictive warnings and semi-automated assistance during specific surgical tasks. Full autonomy is unlikely because it would raise legal responsibility issues for manufacturers in the event of complications. Training supported by video analysis and improved interoperability will also expand.
Q8.	Ethical challenges include unequal access, lack of standardized credentialing, overconfidence among teams with limited robotic experience and unrealistic expectations. Vendor dependency becomes problematic when training quality varies. Remote robotic surgery introduces unclear responsibility for postoperative care and high logistical costs, making routine use unlikely. Autonomous systems would also create unresolved questions about responsibility for clinical decisions.
Q9.	Innovation in the coming decade will focus on artificial intelligence, semi-automation of selected steps, improved usability and decreasing cost. Robotics will become easier to learn due to more intuitive

	interfaces and standardization across platforms. Training will also become more widely accessible early in medical education. Although remote surgery will continue to evolve, its broad adoption is limited by cost and liability.
Q10.	Portugal can benefit from establishing national standards for training and credentialing. Hospitals should introduce robotics gradually, selecting a limited number of surgeons to avoid underutilization and excessive pressure. Structured learning curves and collaboration with experienced proctors are essential. Teams must avoid training too many surgeons at once, because inconsistent use can lead to skills decay and inefficient programs.

2.16 Transcript IR2

Occupation: General Manager

Institution: CMR Surgical

Q#	***Synthesized Response***
Q1.	The respondent is a senior executive at CMR Surgical. The company was founded in Cambridge and is now the second largest global provider of soft tissue robotic systems. The platform competes directly with the market leader and with Medtronic. CMR specializes in general surgery, gynaecology, urology, thoracic surgery, ENT (Ear, Nose, Throat) and paediatric surgery.
Q2.	Robotic surgery represents a natural progression from open surgery to laparoscopy and then to advanced MIS. Robotics maintains the benefits of laparoscopy and adds precision, ergonomics and standardization. It improves surgeon comfort and patient outcomes. The respondent also highlights the growing role of artificial intelligence in making results more predictable.
Q3.	Historically, costs were high due to market monopoly. Competition is now reducing prices and changing the cost-per-case model. Total cost of ownership depends on acquisition and instrument usage. New companies are already lowering operational costs, and the respondent expects the market to become more affordable as adoption increases.
Q4.	Market diversification improves affordability. Hospitals finally have alternatives, which reduces the dominance of older platforms. Entry costs remain high due to engineering complexity, but per case costs are becoming more accessible. True price correction only happens when hospitals actively acquire systems from multiple companies.
Q5.	Successful adoption requires a complete program rather than simply purchasing equipment. CMR provides full training, implementation support, workflow preparation, technical service and maintenance. The goal is to ensure that hospitals receive a safe, reliable and fully supported system.
Q6.	Quality assurance is achieved through structured training and strong installation and maintenance processes. Training is included in the acquisition package and covers surgeons and nurses. Long-term sustainability depends on close collaboration between the hospital and the company and on adherence to validated training and safety protocols.
Q7.	Artificial intelligence is expected to be the next major evolution in robotics. AI will improve standardization, real-time support and safety. Most companies are at early stages, but integration is progressing quickly across the sector.

Q8.	Ethical concerns arise when experienced surgeons underestimate the need to learn the robotic platform from the beginning. Skipping steps can compromise patient safety. Ethical adoption requires structured training and ensuring that the entire team, including nurses, becomes competent before treating patients.
Q9.	Innovation over the next 5 to 10 years will be driven by artificial intelligence. Semi-automation of selected tasks is expected to expand. Systems will become more intuitive and interoperable as software improves.
Q10.	Portugal can benefit from diversifying robotic purchases instead of relying on a single dominant platform. Competition reduces costs and improves sustainability. Robots should be purchased for hospitals that are ready to use them consistently and safely. Adequate training and avoiding underutilization are essential for ethical and efficient adoption.

2.17 Transcript IR3

Occupation: Board Member - MicroPort Medical BV

Institution: MicroPort

Q#	***Synthesized Response***
Q1.	MicroPort Robotic Surgery operates in the soft-tissue robotic market and competes with Intuitive, Medtronic and CMR. It is a China-based manufacturer offering a more affordable platform similar to the Da Vinci system. Differentiating features include stronger imaging, faster robotic response and native tele-surgery capability. The respondent notes that a MicroPort robot was recently acquired by a private hospital group in Porto.
Q2.	Adoption is driven by improved clinical outcomes, fewer readmissions and higher procedural precision. Robotics also increases throughput and strengthens institutional reputation. Patients associate robotics with high-quality care, and surgeons prefer hospitals equipped with advanced systems, making the technology important for talent attraction.
Q3.	The respondent did not describe specific financing models but emphasizes that competition lowers acquisition and usage costs. Improved surgical accuracy, reduced bleeding and shorter recovery contribute to lower overall patient-care costs.
Q4.	Affordability increases through market competition and efficiency gains. Robotics can reduce infections, shorten length of stay and accelerate recovery, supporting sustainability in hospitals with limited resources.
Q5.	Training is adapted to each team's prior experience. Surgeons' familiar with robotic systems receive platform-specific training, while robotic-naïve surgeons undergo additional procedural training. MicroPort relies on external accredited centres such as IRCAD and the Orsi Academy, which it fully supports. No structured performance dashboards or monitoring systems were mentioned.
Q6.	The respondent did not describe formal quality assurance processes, credentialing pathways or governance mechanisms implemented by the company. These aspects were not explicitly addressed in the interview.

Q7.	MicroPort does not collect or store surgical data due to privacy concerns. Surgeons may extract and analyse their own data, but the company does not retain it. AI features or interoperability capabilities were not described in the interview.
Q8.	Ethical concerns include data protection, cybersecurity and compliance with regulations such as GDPR. Another challenge is selecting appropriate patients and procedures; robotic surgery should only be used when it offers added value compared with laparoscopy.
Q9.	Tele-surgery is identified as the major future development, enabling remote access to expert surgeons and expanding care to underserved regions. Artificial intelligence may support surgeons with real-time guidance, although fully autonomous surgery is not expected soon.
Q10.	Portugal can advance by investing in training and expanding the number of experts. The respondent recommends prioritizing cost-effective systems with proven outcomes. Broader national access can attract talent to regions outside major cities, and connecting robotic systems across hospitals may support collaboration and learning.

2.18 Transcript IR4

Occupation: Area Sales Manager - East

Institution: SS Innovations Private Limited

Q#	***Synthesized Response***
Q1.	The respondent explains that SS Innovations was founded by a cardiac surgeon with extensive robotic cardiac experience. The company's mission is to make robotic surgery affordable in countries where existing platforms are prohibitively expensive. In the Indian market, long dominated by Da Vinci, SS Innovations has rapidly expanded, installing more than one hundred and thirty systems in approximately two and a half years, plus additional installations in countries that do not require stringent regulatory approvals. Differentiating features include affordability, broad specialty coverage and a design philosophy created "by a surgeon for surgeons".
Q2.	Adoption is driven by clinical coverage and affordability. The platform supports approximately six specialties including cardiac, thoracic, general surgery, oncology, urology, gynaecology and head and neck surgery, making it a versatile option. Affordability is a major driver in India, where Da Vinci procedures are costly and financially inaccessible for many hospitals and patients. Surgeons also value ergonomics; SS Innovations uses an open-console design that avoids neck strain and finger discomfort associated with other systems, allowing surgeons to work comfortably during long procedures.
Q3.	The respondent highlights affordability as the company's central design principle. Existing systems in India are extremely costly both in acquisition and in per-instrument usage. SS Innovations instruments are significantly cheaper, and unlike other platforms, they do not have usage locks. Surgeons are free to use instruments for additional cases if the components remain intact, which reduces cost per procedure. This flexibility allows hospitals to reduce surgical expenses substantially compared with traditional robotic systems.
Q4.	Affordability will increase further once the system obtains United States FDA or CE approval, expected within the second quarter of the year two thousand twenty-six. The company's model is designed to

	reduce both acquisition and operational costs. Cheaper instruments without usage locks allow hospitals to stretch resources. Because the company was founded by a surgeon, product development focuses on practicality rather than maximizing commercial margins, helping hospitals in resource-limited settings adopt robotics more sustainably.
Q5.	SS Innovations does not currently offer a formal certification program, but provides hands-on training at its facility in Delhi. Surgeons are invited to examine the robot, receive demonstrations, and observe live cases. The company also uses a "robotic bus", a mobile demonstration unit fully equipped with a robotic system, which travels to medical colleges and corporate hospitals to provide training and awareness. The respondent did not mention structured dashboards or performance monitoring tools.
Q6.	The respondent did not describe formal credentialing or institutional governance mechanisms. He emphasizes awareness and early-stage training opportunities rather than structured governance frameworks. A multi-day certification course is planned for upcoming quarters, but is not yet implemented.
Q7.	The respondent states that artificial intelligence currently has limited usefulness in robotic surgery because anatomical variability between individuals makes algorithmic prediction difficult. Although AI is heavily marketed, he believes that meaningful intraoperative guidance remains constrained. The respondent did not describe specific AI features, data analytics tools or interoperability strategies within the SS Innovations platform.
Q8.	Ethical challenges relate mainly to awareness and training availability. India does not mandate robotic-surgery training for medical graduates, creating disparities in preparedness. The company is attempting to increase awareness and access through training programs and mobile demonstrations. Patient selection is also an ethical point: the respondent notes that robotics should not be used for simple procedures where added value is limited.
Q9.	The respondent identifies tele-surgery as the central innovation. SS Innovations has already performed remote procedures over distances greater than ten thousand kilometres and has launched a tele-surgery chair that allows surgeons to operate from their homes if the hospital robot is within approximately fifty to sixty kilometres. Additional developments include an in-house endoscopic scope expected to receive certification by early two thousand twenty-six. He expects more competitors to enter the market, especially from Asia.
Q10.	The respondent notes that differences in policy between India and Portugal limit direct comparisons. He emphasizes the need for awareness-building among clinicians and patients about situations in which robotic surgery provides true value, particularly in complex procedures such as colorectal, pelvic, thoracic and cardiac surgery. Increasing affordability and understanding of benefits can motivate responsible adoption. The respondent suggests that Portugal could expand access beyond major cities and promote greater awareness of robotic advantages to improve uptake.

Appendix 3: Participant Overview

ID	*Category*	*Profession*	*Hospital/ Company*	*Country*
PR1	Portuguese Healthcare Professional -Private Sector	Urologist - Robotic Surgery (Professor, CMS & FMUL)	Hospital da Luz Lisboa	Portugal
PR2	Portuguese Healthcare Professional -Private Sector	Surgeon - Obesity & Metabolic Surgery (Coordinator)	Hospital da Luz Lisboa	Portugal
PR3	Portuguese Healthcare Professional -Private Sector	Nurse Manager - Operating Room (Deputy Role)	Hospital CUF Tejo Lisboa	Portugal
PR4	Portuguese Healthcare Professional -Private Sector	Urologist - Robotic Surgery (Coordinator & Professor, Hospital de Santa Maria)	Hospital CUF Tejo Lisboa	Portugal
PR5	Portuguese Healthcare Professional -Private Sector	Urologist - Robotic Surgery (EBU Examination Committee Member)	Hospital CUF Descobertas Lisboa	Portugal
PR6	Portuguese Healthcare Professional -Private Sector	Nurse - Operating Room (Health Consulting)	Hospital De Santa Maria Porto	Portugal
PS1	Portuguese Healthcare Professional -Public Sector	Surgeon - Hepatobiliary & Robotic Surgery	Hospital Curry Cabral	Portugal
PS2	Portuguese Healthcare Professional -Public Sector	Surgeon - Obesity & Metabolic Surgery (Robotic Surgery Unit)	Hospital Curry Cabral	Portugal
PS3	Portuguese Healthcare Professional -Public Sector	Surgeon - Abdominal Wall & Robotic Surgery (Unit Head)	Hospital Garcia de Orta	Portugal
PS4	Portuguese Healthcare Professional -Public Sector	Surgeon - Colorectal, Oncology, MIS & Robotics	Hospital Garcia de Orta	Portugal
PS5	Portuguese Healthcare Professional -Public Sector	Assistant Doctor - Urology (Senior/Consultant Level)	Hospital Professor Fernando Fonseca	Portugal
PS6	Portuguese Healthcare Professional -Public Sector	Urologist - Prostate Cancer, BPH & Andrology	Hospital Universitário de São João Porto	Portugal
IHP1	International Healthcare Professional - Private sector	Urologist - Robotics, Prostate Cancer & Salvage Therapies (Senior)	Perituskliniken	Sweden
IHP2	International Healthcare Professional- Public Sector	Operating Room Nurse - General Surgery (Registered Nurse)	Linköping university Hospital	Sweden
IR1	Industry Representative	Specialist - Robotic Surgery Start-Up Development	Medtronic	Portugal
IR2	Industry Representative	General Manager	CMR Surgical	Spain
IR3	Industry Representative	Board Member - MicroPort Medical BV	MicroPort	Netherlands
IR4	Industry Representative	Area Sales Manager - East	SS Innovations Private Limited	India

Appendix 4: Integrative Mapping Table (PR/PS, IHP, IR)

Q#	Type	Theoretical Axis	Level	RQ
*Portuguese Healthcare Professionals → **Primary** Analytical Data*				
Q1	PR/PS	Innovation Adoption	Meso	RQ1
Q2	PR/PS	Innovation Adoption	Micro + Meso	RQ1
Q3	PR/PS	Innovation Adoption	Meso + Macro	RQ1
Q4	PR/PS	Innovation Adoption	Macro	RQ1
Q5	PR/PS	Innovation Adoption	Meso + Macro	RQ1
Q6	PR/PS	Innovation Adoption	Meso	RQ1
Q7	PR/PS	Governance & Leadership	Meso	RQ2
Q8	PR/PS	Governance & Leadership	Meso	RQ2
Q9	PR/PS	Governance & Leadership	Meso	RQ2
Q10	PR/PS	Ethical & Trustworthy AI	Micro + Macro	RQ3
Q11	PR/PS	Governance & Leadership	Meso	RQ2
Q12	PR/PS	Innovation + Ethics	Macro	RQ3
*International Healthcare Professionals → **Comparative** Contextual Data*				
Q1	IHP	Innovation Adoption	Meso + Macro	RQ1
Q2	IHP	Innovation Adoption	Micro + Meso	RQ1
Q3	IHP	Innovation Adoption	Meso + Macro	RQ1
Q4	IHP	Innovation Adoption	Macro	RQ1
Q5	IHP	Governance & Leadership	Meso	RQ2
Q6	IHP	Innovation Adoption	Meso	RQ1
Q7	IHP	Governance & Leadership	Meso	RQ2
Q8	IHP	Governance & Leadership	Meso	RQ2
Q9	IHP	Governance & Leadership	Meso	RQ2
Q10	IHP	Ethical & Trustworthy AI	Micro + Macro	RQ3
Q11	IHP	Ethical & Trustworthy AI	Macro	RQ3
Q12	IHP	Innovation + Ethics	Macro	RQ3
*Industry Representatives → **System-level** Contextual Data*				
Q1	IR	Innovation Adoption	Macro + Meso	RQ1
Q2	IR	Innovation Adoption	Meso	RQ1
Q3	IR	Innovation Adoption	Macro	RQ1
Q4	IR	Innovation Adoption	Macro	RQ1
Q5	IR	Governance & Leadership	Meso	RQ2
Q6	IR	Governance & Leadership	Meso + Macro	RQ2
Q7	IR	Ethical & Trustworthy AI	Macro	RQ3
Q8	IR	Ethical & Trustworthy AI	Macro	RQ3
Q9	IR	Innovation + Ethics	Macro	RQ3
Q10	IR	Innovation + Ethics	Macro	RQ3