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Sistematik Derleme/Systematic Review

Artificial Intelligence-Driven Innovation in Cancer Surgery: A Systematic Review of Horizon Europe-Funded Projects

Kanser Cerrahisinde Yapay Zeka Odaklı Yenilik: Ufuk Avrupa Destekli Projelerin Sistematik Bir İncelemesi

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ABSTRACT

Horizon Europe is the European Union's key funding program for research and innovation. It tackles climate change, helps achieve the UN's Sustainable Development Goals, and boosts the EU's competitiveness and growth. This study analyzes AI-driven innovation in cancer surgery through projects funded by the Horizon Europe Program. The systematic review method was used in this study. The methodology for this review was prepared according to PROSPERO. The study adhered to the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" guidelines to ensure comprehensive and transparent reporting. It was found that the projects within this review aim to address a variety of challenges, including improving tumor identification and margin delineation, personalizing treatment plans, and automating surgical procedures. The projects analyzed in this systematic review represent a promising step forward in the development of AI-powered cancer surgery. These projects can significantly impact the field by improving surgical precision, personalizing treatment plans, and automating surgical procedures. The research also underscores the need for continued research and development, particularly in addressing challenges related to data integration, algorithmic transparency, and clinical implementation. As AI continues to permeate the healthcare landscape, its impact on cancer surgery is poised to be profound. The insights gleaned from this study provide a valuable roadmap for future research directions and clinical applications, paving the way for a future where AI empowers health professionals to deliver personalized, effective, and transformative cancer care.

Keywords: Horizon Europe, artificial intelligence, cancer, surgery, European Union

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ÖZ

Horizon Europe, Avrupa Birliği'nin araştırma ve inovasyona yönelik temel finansman programıdır. İklim değişikliğiyle mücadele etmekte, BM'nin Sürdürülebilir Kalkınma Hedefleri'ne ulaşılmasına yardımcı olmakta ve AB'nin rekabet gücünü ve büyümesini artırmaktadır. Bu çalışma, Horizon Europe Programı tarafından finanse edilen projeler aracılığıyla kanser cerrahisinde yapay zeka odaklı inovasyonu analiz etmeyi amaçlamaktadır. Çalışma için sistematik derleme yöntemi kullanılmıştır. Bu derlemenin metodolojisi PROSPERO'ya göre hazırlanmıştır. Çalışma, kapsamlı ve şeffaf raporlama sağlamak için 'Sistematik İncelemeler ve Meta-Analizler için Tercih Edilen Raporlama Öğeleri' kılavuzlarına bağlı kalmıştır. Bu sistematik derlemedeki projelerin; tümör tanımlama ve sınır belirleme, tedavi planlarını kişiselleştirme ve cerrahi prosedürleri otomatikleştirme gibi çeşitli zorlukları ele almayı amaçladığı görülmüştür. Bu sistematik derlemede analiz edilen projeler, yapay zeka destekli kanser cerrahisinin geliştirilmesinde umut verici bir adımı temsil etmektedir. Bu projeler, cerrahi hassasiyeti artırarak, tedavi planlarını kişiselleştirerek ve cerrahi prosedürleri organize ederek alan üzerinde önemli bir etki yaratma potansiyeline sahiptir. Çalışma ayrıca, özellikle veri entegrasyonu, algoritmik şeffaflık ve klinik uygulama ile ilgili zorlukların ele alınmasında sürekli araştırma ve geliştirme ihtiyacının altını çizmektedir. Yapay zeka sağlık hizmetleri ortamına etki etmeye devam ederken, kanser cerrahisi üzerindeki etkisi de oldukça güçlü olacaktır. Bu çalışmadan elde edilen bilgiler, gelecekteki araştırma yönelimleri ve klinik

uygulamalar için değerli bir yol haritası sunarak, yapay zekanın sağlık profesyonelleri için kişiselleştirilmiş, etkili ve dönüştürücü kanser bakımı sunma konusunda güçlendirdiği bir geleceğin zeminini hazırlamaktadır.

Anahtar Kelimeler: Ufuk Avrupa, yapay zeka, kanser, cerrahi, Avrupa Birliği

INTRODUCTION

The European Union (EU) invests in research and innovation through Horizon Europe-The Framework Program for Research and Innovation 2021-2027 to deliver scientific, technological, economic, environmental, and societal impact in pursuit of this general objective and to maximize the added value of the Union's Research and Innovation (R&I) investments, the Union should.[1,2]

Horizon Europe is structured into three foundational pillars, each aligned with distinct objectives corresponding to the program's overarching priorities. The first pillar, designated as "Excellent Science" endeavors to enhance the global scientific competitiveness of the EU. It supports pioneering research initiatives spearheaded by eminent researchers themselves, facilitated through the European Research Council. Additionally, this pillar allocates resources for postdoctoral fellowships, doctoral training networks, and researcher exchanges via the Marie Skłodowska-Curie Actions. Substantial investments are directed toward the development of world-class research infrastructures.[1-3]

The second pillar, denoted as "Global Challenges and European Industrial Competitiveness" is dedicated to advancing research addressing societal challenges while fortifying technological and industrial capacities through specialized clusters. Within this framework, ambitious EU missions are articulated to address significant societal issues. The pillar also encompasses the activities orchestrated by the Joint Research Centre, which provides crucial scientific evidence and technical support to both EU and national policymakers.[3]

The third pillar, titled "Innovative Europe" aspires to position Europe as a leader in fostering market-creating innovation. This objective is pursued through the European Innovation Council (EIC), which supports breakthrough innovations. The European Institute of Innovation and Technology (EIT) operates within this pillar to cultivate the integration of the knowledge triangle encompassing education, research, and innovation, thereby contributing to the overall development of the European innovation landscape.[1,2,4]

Moreover, an integral component of Horizon Europe is the segment dedicated to "Widening Participation and Strengthening the European Research Area". This facet emphasizes augmenting support to EU Member States, aiding them in optimizing their national research and innovation potential.[1,2,5] The implementation of Horizon Europe is augmented by the European Defence Fund, and it is complemented by the Euratom Research and Training program. The budget allocated for Horizon Europe for the period 2021-2027 is approximately €95.5 billion at current prices.[1,6]

Cancer Mission of Horizon Europe Program: Within the Horizon Europe Framework program for Research and Innovation spanning 2021-2027, five missions have been established to address critical challenges facing Europe. Notably, one of these Missions is dedicated to combating cancer. The prevalence of cancer in Europe has surged because of factors such as an aging population, unhealthy lifestyles, and unfavorable social, environmental, and occupational conditions. This surge places a significant burden on citizens, cancer patients, survivors, and their families, and on healthcare systems and society at large. To confront these challenges head-on, the Board for the Mission on Cancer is advocating for an ambitious objective: "By 2030, the aim is to save more than 3 million lives, allowing individuals to lead longer and healthier lives".[6,7]

The mission outline, crafted in collaboration with input from citizens, patients, and stakeholders from Member States, provides 13 recommendations for decisive actions. These actions are designed to enhance our understanding of cancer, its risk factors, and its impact. They also seek to prevent avoidable cases, optimize diagnostics and treatment, and provide comprehensive support to improve the quality of life of individuals living with and beyond cancer. Furthermore, the Mission emphasizes the importance of ensuring equitable access to these measures for all.[6-8] The Board, having outlined the Mission in consultation with stakeholders and citizens, is committed to further engagement across Europe. This ongoing dialog aims to serve as the foundation for defining the necessary actions and strategies essential to realize the ambitious goal of saving lives and improving the well-being of those affected by cancer.[7,8]

Artificial Intelligence (AI) Technology Within The Horizon Europe Program: AI occupies a pivotal position within the Horizon Europe program and the European Commission's broader innovation strategy, serving as a driving force for transformative advancements in research, innovation, and societal well-being. As the European Commission navigates the Horizon Europe landscape, the strategic integration

of AI technologies is a key enabler for tackling complex challenges and fostering sustainable development.[5]

Incorporating AI into Horizon Europe projects enhances data analysis capabilities, accelerates research outcomes, and facilitates evidence-based decision-making, aligning with the European Commission's unwavering commitment to fostering innovation-driven growth. This strategic approach resonates strongly with the Commission's emphasis on leveraging cutting-edge technologies to address global challenges, as articulated in the Horizon Europe framework.[5,6]

By integrating AI into its research and innovation endeavors, the European Commission is poised to harness AI's transformative potential to address pressing societal challenges and foster sustainable development. The integration of AI in health and cancer projects under Horizon Europe enhances the efficiency, accuracy, and impact of research and healthcare interventions, ultimately contributing to the overarching goals of improving public health and addressing societal challenges. This study analyzes AI-driven innovation in cancer surgery through projects funded by Horizon Europe.

METHODS

The purpose of this systematic review is to answer the following questions;

1. What are the topics of projects funded in the field of cancer surgery that involve AI technologies?

2. Under which frame program were these projects funded?

3. What is the duration of the projects?

4. Which countries were funded?

The methodology of this review was prepared according to PROSPERO, but it was not registered in PROSPERO. The study adhered to the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' guidelines to ensure comprehensive and transparent reporting[9].

Search Strategy

The data collection process was conducted using the European Commission's Official Database platform, The Community Research and Development Information Service (CORDIS).

The CORDIS serves as the European Commission's primary gateway to the wealth of knowledge and innovation generated by EU-funded research projects. From FP1 to Horizon Europe, CORDIS has compiled a comprehensive and structured repository of project information, encompassing project factsheets, participant details, reports, deliverables, and links to open-access publications. To further facilitate user access to relevant research findings, CORDIS produces an array of publications and articles. While the print editions are available in English, the web versions are multilingual, catering to users in French, German, Italian, Polish, and Spanish.[10]

Managed by the Publications Office of the European Union on behalf of the European Commission's research and innovation Directorates-General, Executive Agencies, and Joint Undertakings, CORDIS benefits from the expertise of specialized contractors for editorial, data, and technical services. As a cornerstone of the Commission's strategy for disseminating and exploiting research results, CORDIS operates under the governance and funding framework of the Horizon Europe framework program. Through its commitment to providing a comprehensive and user-friendly platform for accessing EU-funded research and innovation outcomes, CORDIS empowers researchers, innovators, and the wider public to leverage the transformative power of research for societal progress.[5,10]

In the study, a two-way keyword strategy was used using "Artificial Intelligence" and "cancer surgery" as different search groups. To optimize retrieval, the Boolean operator "AND" was used to combine these groups of keywords. Search terms were carefully tailored to conform to the specific requirements of the database used. In the CORDIS Platform, the filters "projects" in the Content-Collection area and "Horizon Europe" in the Content-Program area were used. To ensure the validity of the findings, the searches were meticulously re-executed before the final analyses. Only studies that met the predefined inclusion criteria were retained for further evaluation.

Study Selection

Following the electronic database search, a comprehensive verification process was undertaken to eliminate duplicate literature items. Subsequently, the projects identified through the search strategy were meticulously scrutinized, with particular attention paid to titles, objectives, abstracts, funding programs, dates, and project identification numbers. This rigorous assessment served to determine which projects warranted full-text review. Projects deemed relevant on the basis of the established criteria were then subjected to a thorough examination.

Inclusion and Exclusion Criteria

This review focuses on elucidating the landscape of available research projects on AI-driven cancer surgery. The review meticulously examined studies that met the following criteria:

1. Relevance to AI-powered cancer surgery: The primary focus was on studies that explicitly employed AI techniques or methodologies in the context of cancer surgery.

This ensured that only studies directly addressing the application of AI in cancer surgery were included.

2. Funding under Horizon Europe: This review exclusively considered studies that received financial support through the Horizon Europe framework program. This restriction ensured a consistent and well-defined funding source, allowing for a more focused assessment of the current state of AI-driven cancer surgery research within this specific funding framework.

3. Project-based approach: This review encompassed individual projects that delved into the application of AI in cancer surgery. This project-based approach provides a granular perspective on the current state of research in this rapidly evolving field, allowing for a deeper understanding of the specific contributions and advancements made by individual projects.

To maintain the integrity of the review, certain types of information were excluded:

1. Project reports, result packs, results in brief, project information packs, and project news: While these materials provide valuable insights into individual projects, they do not constitute primary research findings. Excluding these materials ensured that the review focused on the most rigorous and impactful research outputs.

2. Projects funded by other frame programs: The review maintained a strict focus on projects funded under the Horizon Europe program to ensure a cohesive dataset. Excluding projects funded by other programs allowed for a more focused analysis of the specific contributions made by Horizon Europe-funded research to the field of AI-driven cancer surgery.

3. Projects with no relationship to AI-used cancer surgery: This review excluded projects that did not directly address the application of AI in cancer surgery. This ensured that only studies relevant to the central theme of the review were included, maintaining the focus and coherence of the analysis.

By adhering to these rigorous inclusion and exclusion criteria, the review effectively captured the current state of knowledge regarding AI-driven cancer surgery within the Horizon Europe framework program.

Data Extraction and Synthesis

Following a thorough review, a structured dataset was extracted using a standardized data extraction form. This dataset includes project titles, unique identifications, project descriptions, start and end dates, coordinating countries, and relevant financing programs. The extracted data were meticulously tabulated using established methods. To facilitate a clear and organized presentation, the data are categorized under three separate headings: "AI-enabled tools for real-time tumor identification and demarcation during surgery", "AI-enabled tools to assist treatment planning" and "automating surgical procedures".

RESULTS

An initial electronic database search yielded 1112 projects that potentially met the inclusion criteria. Following a rigorous screening process, 26 projects were deemed relevant for further evaluation. Of the 26 selected projects, 9 were subjected to a comprehensive full-text review to assess their eligibility for inclusion. The selection process was guided by stringent criteria to ensure the inclusion of high-quality and pertinent research. The systematic search strategy employed in this review is depicted clearly and concisely in Figure 1. The flowchart illustrates the stepwise selection process, from the initial electronic database search to the final selection of studies for full-text review. Tables 1 and 2 provide a detailed overview of data extraction (Table 1) and the characteristics of the included studies (Table 2).

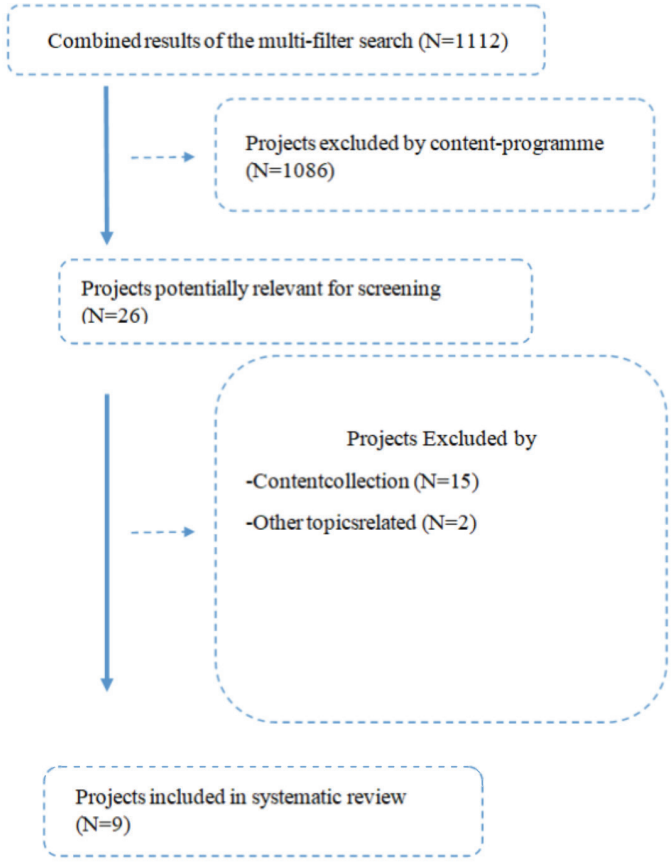

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of the literature search process

Table 1. Data extraction

No	Project title	ID number	Project description	Start and end date	Coordinator country	Funding program
01	CINDERELLA-Clinical Validation of an AI-based approach to improve the shared decision-making process and outcomes in Breast Cancer Patients proposed for Locoregional treatment	101057389	Breast-conserving surgery and mastectomy, with or without subsequent breast reconstruction or lymph node removal, represent viable therapeutic options for breast cancer patients. Furthermore, radiotherapy is often employed to enhance locoregional control. Despite these interventions, there remains a notable absence of methodologies capable of replicating the aesthetic consequences ensuing from locoregional treatments for breast cancer. Addressing this gap, the CINDERELLA project proposes the development of a user-friendly application utilizing AI. This application leverages a comprehensive clinical database, employing both picture and biometric matching techniques to generate simulated images that afford patients a visual approximation of the anticipated surgical outcomes. The CINDERELLA APProach platform is designed to fortify the active involvement of patients in the clinical decision-making process.	1 June 2022 31 May 2026	Portugal	HORIZON.2.1 Health2.1.5-Tools, Technologies, and Digital Solutions for Health and Care, including personalized medicine
02	CLASSICA-AI-assisted cancer analysis during surgery	101057321	CLASSICA proposes a novel digital analysis technique for real-time intraoperative cancer identification and surgical guidance. Leveraging perfusion imaging within the initial post-dye administration window, the method tracks and compares perfusion patterns within the endo-laparoscopic field of view. This approach, empowered by real-time AI-assisted analysis, facilitates immediate, individualized surgical decision-making. Funded by the European Union, the CLASSICA project aims to refine the existing AI-powered analysis prototype into a clinically viable tool for the operating room. The project will meticulously evaluate the tool's performance, reliability, and user acceptance through rigorous testing within five prominent European cancer centers. The validation process will encompass diverse surgical applications, including: Biopsy and tumor identification, optimization of large rectal polyp resection, addressing other challenging surgical scenarios. By successfully validating the AI-assisted analysis tool across these diverse surgical settings, the CLASSICA project holds significant promise for revolutionizing cancer surgery by enabling real-time, data-driven decision-making at the point of care.	1 May 2022 30 April 2026	Ireland	HORIZON.2.1-Health HORIZON.2.1.5-Tools, Technologies, and Digital Solutions for Health and Care, including personalized medicine
03	TRAIFAC-Transforming Radiology with AI to Fight Abdominal Cancer	101113932	The TRAIFAC project proposes a novel framework for seamless integration of AI into the existing imaging workflow of radiologists. This approach, characterized by a "zero-click" design philosophy, aims to revolutionize abdominal lesion detection and classification through the automatic presentation of relevant information to radiologists. By optimizing information accessibility and streamlining workflow, TRAIFAC has the potential to significantly improve the identification of precursor lesions, potentially reducing the need for invasive diagnostic procedures and surgeries. This reduction in invasive interventions could demonstrably mitigate patient complications and contribute to improved quality of life, particularly for individuals with abdominal lesions exhibiting a low risk of malignant progression.	1 June 2023 30 November 2023	Spain	HORIZON.3.2-European Innovation Ecosystems

Table 1. C ontinued

No	Project title	ID number	Project description	Start and end date	Coordinator country	Funding program
04	MIRACLE-Metabolic MRI-as-a-Service for oncologic care	101058125	The principal goal of the MIRACLE project is the conceptualization and realization of a supplementary apparatus designed for integration with magnetic resonance imaging scanners. This innovative add-on device aims to facilitate virtual biopsies, offering crucial insights into tumor margins with the dual purpose of refining surgical interventions and furnishing metabolic data for enhanced therapeutic strategies. The envisaged outcome of this precise and expeditious non-invasive procedure is the provision of comprehensive information to clinicians, empowering them to formulate individualized treatment regimens tailored to specific patient profiles and tumor characteristics. In pursuit of this objective, the project specifically endeavors to engineer both the requisite breast coil hardware and accompanying software, employing breast cancer as a prototypical case for methodical evaluation and validation.	1 May 2022 30 April 2025	Netherland	HORIZON.3.1-The European Innovation Council (EIC)
05	FLUAR FLUAR-A novel solution for fluorescence-guided surgery based on AR	190144382	FLUAR represents an innovative iteration of AR glasses equipped with integrated state-of-the-art NIR sensors and advanced computer vision algorithms. These AR glasses are designed to discern and visually present fluorescent biomarkers within the direct line of sight of surgeons, thereby illuminating tumor margins on the designated target. The integration of FLUAR is anticipated to elevate surgical precision and concurrently diminish the duration of tumor removal procedures. The overarching objective of this initiative is to conclude the technical advancements of FLUAR and substantiate its clinical applicability following the stipulated requirements of end-users.	1 April 2023 31 March 2025	Luxembourg	HORIZON.3.1-The European Innovation Council (EIC)
06	CHARM-Chemometric histopathology via coherent Raman imaging for precision medicine	101058004	The objective of the CHARM project is to advance the field of cancer digital histopathology by introducing a technology that can assess the molecular composition of tissues and characterize tumors in a label-free manner. The project aims to develop a medical instrument centered on a broadband coherent Raman scattering microscope, augmented by an integrated AI module grounded in deep learning, statistical methodologies, and machine learning algorithms. Through this amalgamation with AI, the project seeks to establish a rapid and dependable clinical DSS tailored for cancer diagnosis and personalized therapeutic interventions. The envisaged chemometric pathology system is designed to analyze unstained tissues, demonstrating a capability to identify tumors with an accuracy exceeding 98% and predict tumor diagnoses with an accuracy surpassing 90%.	1 May 2022 31 October 2025	Italy	HORIZON.3.1-The European Innovation Council (EIC)

Table 1. C ontinued

No	Project title	ID number	Project description	Start and end date	Coordinator country	Funding program
07	METASTRA-Computer-Aided Effective Fracture Risk Stratification of Patients with Vertebral Metastases For Personalised Treatment Through Robust Computational Models Validated in Clinical Settings	101080135	This undertaking seeks to develop computational models rooted in AI and VPH principles, specifically tailored for biomechanical analyses, with the primary objective of stratifying patients afflicted with spine metastasis at a heightened risk of fracture. Furthermore, these models aim to discern optimal personalized surgical interventions. Leveraging a comprehensive dataset encompassing clinical information from 2000 retrospective cases and biomechanical data derived from 120 ex vivo specimens, an intensive model training regimen will be implemented. Subsequently, the efficacy of the newly devised approach will be assessed in a multicentric prospective observational study involving 200 patients. The resulting models will be integrated into a DSS, empowering clinicians to proficiently stratify metastatic patients. To ensure compliance with regulatory standards and facilitate future utilization, meticulous attention will be given to the design of both the models and the DSS. Beyond its immediate clinical applications, this project holds the potential to institute novel guidelines governing the stratification and management of metastatic patients.	1 July 2023 30 June 2028	Italy	HORIZON.2.1-Health HORIZON.2.1.5-Tools, Technologies, and Digital Solutions for Health and Care, including personalized medicine
08	PhosPrints-Laser bioprinting device and *in vivo* applications	190195672	The PhosPrint bioprinter system is affiliated with established protocols for the isolation of cells from autologous biopsies, subsequent *in vitro* cell expansion, and *in vivo* cell printing. Representing an innovative paradigm, this approach facilitates real-time tissue engineering and repair, particularly tailored for intricate medical conditions. The incorporation of D-LIB capabilities is anticipated to inaugurate the integration of laser bioprinting technology into surgical operations. This implementation will commence with the application of enterocystoplasty/augmentation in cystectomy bladder cancer patients, serving as the designated go-to-market application.	1 May 2023 30 April 2025	Greece	HORIZON.3.1-The European Innovation Council (EIC)
09	FADEQ-Fully automated cfDNA extraction and quantification-liquid biopsies safely from Patient to Lab		Liquid biopsies, characterized as blood tests, show increasing potential for diagnostic applications, particularly in cancer and prenatal screening. The full realization of this potential is hampered by pre-analytical challenges, in particular the requirement for a competent workforce and strict logistical prerequisites related to sample transport. In response to these technical barriers, the project has developed a methodology focussing on immediate and automated sample processing. This innovative approach aims to deliver samples with high reliability, reduce human labor involvement, and alleviate transport requirements. The key innovation, called FADEQ, is a fully automated single-use cartridge. This proprietary system uses a special hollow fiber membrane for blood filtration followed by isolation of cfDNA from plasma within a microfluidic framework. The integration of such developments aims to streamline and optimise liquid biopsy procedures, address critical challenges in sample processing, and improve the efficiency of diagnostic methodologies.	1 April 2022 31 March 2025	Finland	HORIZON.3.1-The European Innovation Council (EIC)

AI: Artificial intelligence, AR: Augmented reality, NIR: Near-infrared, VPH: Virtual Physiological Human, DSS: Decision Support System, cfDNA: Cell-free DNA

Table 2. Characteristics of the projects
Project Title: Clinical Validation of an AI-based approach to improve the shared decision-making process and outcomes in Breast Cancer Patients proposed for Locoregional treatment, AI-assisted cancer analysis during surgery, Transforming Radiology with Artificial Intelligence to Fight Abdominal Cancer, Metabolic MRI-as-a-Service for oncologic care -Novel diagnostic platform for virtual biopsy, A novel solution for fluorescence-guided surgery based on augmented reality, CHARM: Cutting-edge AI-Powered Chemometric Pathology for Cancer Diagnosis and Personalised Therapy, Computer-Aided Effective Fracture Risk Stratification of Patients with Vertebral Metastases For Personalised Treatment Through Robust Computational Models VValidated in Clinical Settings, Laser bioprinting device and *in vivo* applications, Fully automated cfDNA extraction and quantification-liquid biopsies safely from Patient to Lab
Acronyms: CINDERELLA, CLASSICA, TRAIFAC, MIRACLE, FLUAR, CHARM, METASTRA, PhosPrint, FADEQ
Project ID: 101057389, 101057321, 101113932, 101058125, 190144382, 101058004, 101080135, 190195672, 101112429
Project Description: Develop an AI-based application to simulate the aesthetic outcome of surgery for breast cancer patients, Develop an AI-assisted solution for real-time tumor identification and margin delineation during surgery, Develop an AI-powered tool to assist radiologists in detecting and classifying abdominal lesions, Develop an AI-based add-on device for MRI scanners to enable virtual biopsies, Develop AR glasses with integrated NIR sensors and AI algorithms to enhance FGS, Develop an AI-powered histopathology system for label-free tissue characterization, Develop AI-and physiology-based biomechanical computational models to stratify patients with spine metastasis, Develop a laser bioprinting technology for real-time tissue engineering/repair, Develop a fully automated disposable cartridge for cfDNA extraction and quantification
Start Date: 1 June 2022, 1 May 2022, 1 June 2023, 1 May 2022, 1 April 2023, 1 May 2022, 1 July 2023, 1 May 2023, 1 April 2022
End Date: 31 May 2026, 30 April 2026, 30 November 2023, 30 April 2025, 31 March 2025, 31 October 2025, 30 June 2028, 30 April 2025, 31 March 2025
Coordinator Country: Portugal, Ireland, Spain, Netherlands, Luxembourg, Italy, Italy, Greece, Finland
Funding Program: HORIZON.2.1 -Health, HORIZON.2.1 -Health, HORIZON.3.2 -European Innovation Ecosystems, HORIZON.3.1 -The European Innovation Council (EIC), HORIZON.3.1 -The European Innovation Council (EIC), HORIZON.3.1 -The European Innovation Council (EIC), HORIZON.2.1 -Health, HORIZON.3.1 -The European Innovation Council (EIC), HORIZON.3.1 -The European Innovation Council (EIC)
AI: Artificial intelligence, AR: Augmented reality, NIR: Near-infrared, cfDNA: Cell-free DNA, MRI: Magnetic resonance imaging

Table 2 summarizes the key elements of each study, including topics, duration, leading countries, ID numbers, and funding programs.

The projects are focused on various challenges, including AI-enabled tools for real-time tumor identification and demarcation during surgery.[11,12] AI-enabled tools to assist treatment planning and automate surgical procedures.[13-19] Three of the projects were funded under the HORIZON.2.1-Health funding program, five were funded under the HORIZON.3.1-The EIC funding program and was funded under the HORIZON.3.2-European Innovation Ecosystems funding program.[11-19] The projects are being carried out by researchers in eight different EU countries: Italy, Spain, Finland, Greece, Ireland, Luxembourg, Netherlands, and Portugal.[11-18] The projects have a duration of between 1-2 years and 5 years.[11-19]

Topics Covered: The nine projects summarized in the data extraction and synthesis table represent a diverse and promising array of AI-powered approaches to cancer surgery. These projects address several challenges in the field, from improving tumor identification and margin delineation to personalizing treatment plans and automating surgical procedures.

Several of these projects focus on developing AI-assisted tools for real-time tumor identification and margin delineation during surgery. These tools can significantly improve surgical precision and reduce the risk of recurrence.[11,12] For instance, the CLASSICA project is developing an AI-powered solution that can identify tumors and delineate margins in real time, while the FLUAR project is developing AR glasses that can overlay tumor margins onto the patient's anatomy.[11,12]

There are projects focused on developing AI-powered tools to assist in treatment planning.[13,14,17,18] The MIRACLE project, for instance, is developing an AI-powered add-on device for magnetic resonance imaging (MRI) scanners that can enable virtual biopsies, providing valuable information for treatment planning.[13] The TRAIFAC project is developing an AI-powered tool to assist radiologists in detecting and classifying abdominal lesions, which can help identify patients who may benefit from specific treatment options.[14] Other projects have focused on automating surgical procedures.[15,16,19] The PhosPrint project is developing a laser bioprinting technology for real-time tissue engineering/repair, which can automate some aspects of surgery.[15] The FADEQ project is developing a fully automated disposable cartridge for cell-free DNA (cfDNA) extraction and quantification, which could automate some of the preoperative work in cancer surgery.[16] METASTRA will develop AI-and physiology-based (VPH) biomechanical

computational models to stratify patients with spine metastasis who are at high risk of fracture and to identify the best personalized surgical treatment.[19]

Funding Program: The Health Cluster within Horizon Europe aims to generate novel insights and pioneer inventive solutions to safeguard the health and welfare of individuals. The 2023-2024 work program in Cluster 1 "Health" aligns with two Key Strategic Orientations (KSOs) outlined in Horizon Europe's strategic plan for 2021-2024. Specifically is dedicated to advancing the vision of establishing a more resilient, inclusive, and democratic European society (KSOD) and championing open strategic autonomy by spearheading the advancement of pivotal digital, enabling, and emerging technologies, sectors, and value chains (KSO-A).[20] In this research, three projects (CINDERELLA, CLASSICA, and METASTRA) were funded under HORIZON.2.1 -Health Program.[11,17,19]

The EIC, a novel initiative within Horizon Europe, is designed to facilitate the growth and expansion of deep-tech start-ups and scale-ups in Europe. This program offers financial assistance and comprehensive support to innovators throughout their entire trajectory, spanning the initial research stages to the market launch phase.[21] Five projects (MIRACLE, FLUAR, CHARM, PhosPrint, FADEQ) were funded under the EIC program within this research. The EIT collaborates with forward-thinking initiatives under Horizon Europe and various EU funding programs.[12,13,15,16,19] This collaborative endeavor strengthens the broader innovation ecosystem in Europe. The EU's goal is to establish cohesive and efficient innovation ecosystems that support company development, encourage innovation, and foster collaboration among innovation stakeholders on national, regional, and local scales.[22] One project (TRAIFAC) is funded under European Innovation Ecosystems within the scope of this research.[14]

Project Coordinator Countries: Project coordinator countries are analyzed as follows: Italy-2 projects (CHARM, METASTRA), Spain-1 project (TRAIFAC), Finland-1 project (FADEQ), Greece-1 project (PhosPrint), Ireland-1 project (CLASSICA), Luxembourg-1 project (FLUAR), Netherlands-1 project (MIRACLE), Portugal-1 project (CINDERELLA).[11-19]

Duration: The duration of projects was analyzed as follows; 1-2 years, 2 projects (FLUAR, FADEQ)**;** 2-3 years, 5 projects (CINDERELLA, CLASSICA, MIRACLE, TRAIFAC, PhosPrint); 4-5 years, 2 projects (METASTRA, CHARM).[11-19]

These nine projects represent a diverse range of AI-powered approaches to cancer surgery. The projects address various challenges, including improving tumor identification and margin delineation, personalizing treatment plans, and automating surgical procedures. The projects are still in the early stages of development, but they can significantly impact the field of cancer surgery.

DISCUSSION

The nine AI-powered cancer surgery projects analyzed in this research represent a promising step forward in the development of this field. These projects address various challenges, from improving tumor identification and margin delineation to personalizing treatment plans and automating surgical procedures.

Some projects focus on developing AI-assisted tools for real-time tumor identification and margin delineation during surgery. These tools can significantly improve surgical precision and reduce the risk of recurrence. For instance, the CLASSICA project is developing an AI-powered solution that can identify tumors and delineate margins in real time, while the FLUAR project is developing AR glasses that can overlay tumor margins onto the patient's anatomy.[11,12] Existing research corroborates the findings of this study, demonstrating that AI-assisted colonoscopy can address significant shortcomings in colon cancer detection.[23] Similarly, AI is revolutionizing breast surgery by enhancing surgical techniques and introducing novel surgical approaches.[24,25]

In this study, projects are focused on developing AI-powered tools to assist in treatment planning. The MIRACLE project, for example, is developing an AI-powered add-on device for MRI scanners that can enable virtual biopsies, providing valuable information for treatment planning.[13] The TRAIFAC project is developing an AI-powered tool to assist radiologists in detecting and classifying abdominal lesions, which can help identify patients who may benefit from specific treatment options.[14] There are various studies in the literature in which modern technologies such as virtual reality and infrared technology are used as a tool to guide surgical procedures. Recent advances in surgical technology have significantly enhanced the precision and efficacy of surgical interventions while simultaneously fostering an improved work environment for surgical teams.[13,14,18,26-28]. This review makes a valuable contribution to the field by synthesizing the existing literature and providing new insights.

Projects are focused on automating surgical procedures. The PhosPrint project is developing a laser bioprinting technology for real-time tissue engineering/repair, which can automate some aspects of surgery.[15] The FADEQ project is developing a fully automated disposable cartridge for cfDNA extraction and quantification, which could automate some of the preoperative work in cancer surgery.[16] The deployment of AI in automating procedures in healthcare is fraught with technical challenges and engineering complexities, while its legal and ethical considerations demand a nuanced and well-considered approach.[29,30] A thorough exploration of the opportunities

and obstacles posed by AI in the context of future work is essential for alleviating its adverse consequences on healthcare, health, and overall well-being.[31]

The project durations within the Horizon Europe program are contingent upon the specific work packages and their associated timelines.[5,20,21] The duration of projects within this study varies from one to five years, reflecting the complexity and scope of the research undertakings. This range in duration allows for a balanced approach, ensuring that both short-term and long-term goals are addressed.

The projects summarized in this review demonstrate the global reach of AI-powered cancer surgery research. Researchers from eight different EU countries are collaborating on these projects, representing Italy, Spain, Finland, Greece, Ireland, Luxembourg, Netherlands, and Portugal. Upon examining the executing countries of the projects encompassed within this study, it was revealed that they were exclusively developed European countries. The "widening participation" component of the Horizon Europe program is specifically designed to empower other countries to reap greater benefits from the program. Under this initiative, program countries beyond developed European nations are provided with the necessary support to achieve equitable access to the opportunities offered by the Horizon Europe Program.[5,32] This international collaboration fosters knowledge sharing and expertise exchange, accelerating progress in this field.

The projects analyzed in this systematic review represent a promising step forward in the development of AI-powered cancer surgery. These projects can significantly impact the field by improving surgical precision, personalizing treatment plans, and automating surgical procedures.

CONCLUSION

The findings highlight the transformative potential of AI in enhancing surgical precision, optimizing treatment planning, and improving patient outcomes. The review also underscores the need for continued research and development, particularly in addressing challenges related to data integration, algorithmic transparency, and clinical implementation. As AI continues to permeate the healthcare landscape, its impact on cancer surgery is poised to be profound. The insights gleaned from this review provide a valuable roadmap for future research directions and clinical applications, paving the way for a future where AI empowers surgeons to deliver personalized, effective, and transformative cancer care.

As AI-powered cancer surgery continues to develop, there are several important areas for future research. One important area of focus is the development of AI algorithms that can learn from large datasets of clinical data to become more accurate and reliable and better adapt to the individual needs of each patient. Another important area of focus is the development of AI-powered tools that can be integrated into the existing surgical workflow to make the surgical process easier for surgeons to adopt AI technologies and ensure that AI is used safely and effectively. This approach will help to ensure that the benefits of AI-powered cancer surgery are available to everyone, regardless of their location or socioeconomic status.

Ethics

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