ISRG Journal of Arts, Humanities and Social Sciences (ISRGJAHSS)

ISRG PUBLISHERS

Abbreviated Key Title: ISRG J Arts Humanit Soc Sci

ISSN: 2583-7672 (Online)

Journal homepage: https://isrgpublishers.com/isrgjahss

Volume – IV Issue - IV (July – August) 2026

Frequency: Bimonthly

REVISITING IBN AL-HAYTHAM'S OPTIC: AN EPISTEMOLOGICAL FOUNDATION FOR CONTEMPORARY PRECISION MEDICINE

Wanto[1*], Desi Natalia Nurkhasanah[2], Ridwan[3], Suparjo[4]

[1, 2, 3, 4] State Islamic University Prof. K.H. Saifuddin Zuhri Purwokerto, Indonesia

| **Received:** 03.07.2026 | **Accepted:** 09.07.2026 | **Published:** 13.07.2026

*__Corresponding author:__ Wanto

Abstract

This article reconstructs the optical epistemology of Ibn al-Haytham as a foundational conceptual framework for the advancement of contemporary precision medicine. Navigating the paradigm shift in medical science toward highly personalized, data-driven frameworks predicated on patient-specific biological characteristics, this study highlights the role of light as a primary scientific medium within modern optical imaging modalities. Utilizing a library-based inquiry driven by a historical-epistemological approach and a conceptual-comparative analysis, this paper evaluates how the fundamental principles of Ibn al-Haytham's optics, specifically controlled observation, systematic experimentation, geometric propagation, and the critique of speculative dogmatism, configured the scientific methodology of conceptualizing light as an instrument of knowledge production. The findings indicate that the paradigm shift of light, from an ancillary visual tool to an epistemic medium for decoding biological reality, exhibits a profound conceptual continuity with contemporary optical imaging practices in precision medicine, such as optical coherence tomography (OCT), fluorescence imaging, Raman spectroscopy, photoacoustic imaging, and near-infrared (NIR)-based techniques. This article contends that Ibn al-Haytham's intellectual legacy remains indispensable to the historiography of Islamic science, the philosophy of science, and the epistemological reflection undergirding modern medical developments. Consequently, this study offers an integrative perspective that converges the history of science, the philosophy of knowledge, and light-based biomedical innovations.

Keywords: Ibn al-Haytham; Optics; Epistemology; Precision Medicine; Optical Imaging

INTRODUCTION

The advent of precision medicine in the twenty-first century marks a significant paradigm shift in medical science, transitioning from a standardized, one-size-fits-all model toward diagnostic and therapeutic frameworks that increasingly rely on patient-specific biological characteristics.

Within this context, optical imaging technologies play a pivotal role due to their capacity to visualize the morphological, physiological, and molecular features of living tissues in a non-invasive, real-time, and highly secure manner. Furthermore, optical imaging has been widely integrated into biomedical applications within the near-infrared spectrum, owing to its operational flexibility, ease of deployment, and capability to discern biological alterations without the prerequisite of contrast agents in numerous scenarios (Ghasemi et al. 2016). Consequently, light is no longer conceptualized merely as a medium of illumination, but rather as a primary instrument for the production of biological and clinical knowledge.

Quantitatively, the advancements in contemporary optical technology demonstrate compelling milestones. Optical coherence tomography (OCT), for instance, can achieve an axial resolution of approximately 1–15 μm, with certain state-of-the-art systems reporting resolutions of around 5 μm alongside high A-scan speeds, making it exceptionally effective for dissecting tissue microstructures (Fujimoto et al. 2000). Photoacoustic imaging (PAI) has also demonstrated substantial clinical progress, exemplified by its capability to perform whole-breast scanning within roughly 12 seconds in contemporary configurations. Concurrently, second near-infrared window (NIR-II) fluorescence imaging approaches underscore that optical imaging is steadily progressing toward enhanced tissue depth, superior spatial resolution, and optimized signal-to-background ratios. These empirical metrics demonstrate that light has evolved into an increasingly precise scientific medium for interrogating and decoding the human body.

However, beneath these technological triumphs lies a critical conceptual issue: the evolution of modern optical technology is frequently discussed as though it emerged solely from contemporary technological leaps, isolated from any substantive connection to the historical epistemology of light. In reality, the profound efficacy of optical imaging resides precisely in its fundamental principle, namely, the capacity of light to carry, reflect, scatter, and map information from objects hidden from direct ocular vision. The core problem is not merely how the body can be visualized, but how light itself is understood as a scientific language that translates biological reality into measurable, analytical, and validated formats. From this standpoint, the history of optics serves as a foundational conceptual bedrock for modern medical science.

In the history of science, Ibn al-Haytham occupies a seminal position by systematically synthesizing observation, hypothesis, and experimentation into a coherent scientific workflow. His magnum opus, *Kitab al-Manazir* (The Book of Optics), is widely recognized as both an experimental and mathematical inquiry into light and vision, and a rigorous critique of classical Greek visual theories that relied heavily on speculative authority. Recent literature continues to affirm that his scientific legacy remains vital to the history of optics and shapes the modern understanding of verification, proof, and reproducibility in science (Sabra and Hogendijk 2023). Consequently, Ibn al-Haytham stands as one of the early architects of the scientific method, linking optical phenomena to a structured framework of quantifiable knowledge.

A considerable body of prior literature has examined Ibn al-Haytham from diverse perspectives. Scholarly inquiries have emphasized the contemporary significance of his works for modern science and technology, analyzed his scientific method as a cornerstone for verification and validation (Rehman et al. 2021), and discussed his relevance to perceptual distance theories alongside his broader influence within the discourse of the history of science (Sedgwick 2022). Other studies have even aligned Ibn al-Haytham's biography and scholarship with Islamic methodological traditions, postulating parallels between validation procedures in Islamic studies and his empirical scientific mechanics. While this varied scholarship demonstrates that rereading Ibn al-Haytham remains highly generative, the existing discourse remains predominantly confined to historical, biographical, or generalized epistemological dimensions.

It is precisely at this juncture that the research gap becomes apparent. Limited research has specifically reconstructed the optical epistemology of Ibn al-Haytham to conceptually link it with the scientific architecture of precision medicine, particularly within modern optical imaging modalities such as OCT (Moghadam et al. 2025), fluorescence imaging (Schouw et al. 2021), Raman spectroscopy (Khristoforova, Bratchenko, and Bratchenko 2023), photoacoustic imaging (Riksen, Nikolaev, and van Soest 2023), and near-infrared (NIR)-based techniques (Bec, Grabska, and Huck 2020). Although extant studies have demonstrated how optical imaging is currently deployed to decipher anatomical, functional, and molecular processes in vivo, few have utilized classical optical heritage as an analytical lens to decode the scientific logic undergirding these practices. In other words, the underexplored intellectual terrain lies in the epistemic continuity between the classical comprehension of light and its contemporary exploitation as a diagnostic instrument.

Addressing this gap, the novelty of this article lies in its endeavor to reconstruct Ibn al-Haytham's optics not merely as a historical milestone, but as an enduring conceptual foundation that illuminates the operational logic of modern precision medicine. This study does not intend to oversimplify historical relations into claims of linear causality; rather, it traces structural correspondences within knowledge production: light as the medium, biological objects as the deciphered reality, and quantifiable observation as the prerequisite for scientific validity. Through this framework, this article aims to converge the history of science, the philosophy of science, and medical technology into a more holistic and generative discourse.

The urgency of this study is underscored by the fact that contemporary precision medicine no longer hinges solely on technological sophistication, but on the epistemological precision of understanding how biological data is produced through the interaction of light and tissue. If light is treated merely as a technological tool, its historical, philosophical, and methodological dimensions become untethered from their generative roots. Conversely, by tracing these elements historically and conceptually, the evolution of optical imaging can be understood as part of the broader trajectory of human scientific rationality. Therefore, this inquiry is significant both as a contribution to the historiography of Islamic science and as an enrichment of scientific reflection within science education, the philosophy of science, and modern biomedicine. By placing Ibn al-Haytham in dialogue with precision medicine, this article endeavors to offer a more meticulous, balanced, and relevant perspective for the advancement of contemporary knowledge.

RESEARCH METHOD

This study is a library-based inquiry that employs a historical-epistemological approach, supported by conceptual-comparative analysis (Adlini et al. 2022). This methodological framework was selected because the primary objective is to reconstruct the epistemological structure of Ibn al-Haytham's optics based on

DOI: 10.5281/zenodo.21331159

authoritative academic literature, while analyzing its conceptual relevance to the advancement of contemporary precision medicine. Consequently, this research positions the history of science as a critical analytical matrix to elucidate the epistemic continuity of scientific ideas bridging classical optical traditions and modern medical imaging technologies.

The research data are derived entirely from qualitative desk-based documentation. The primary literature consists of academic monographs, peer-reviewed international journal articles, and diverse scholarly publications that specifically address Ibn al-Haytham's optical thought, the historical evolution of optics, scientific methodology within the Islamic tradition, and his contributions to modern science. Supplementary literature encompasses state-of-the-art articles regarding optical imaging, optical coherence tomography (OCT), fluorescence imaging, Raman spectroscopy, photoacoustic imaging, near-infrared spectroscopy, biophotonics, and precision medicine. All sources were selected through purposive sampling, prioritizing substantive relevance to the research focus, academic credibility, the institutional authority of the publishers, and chronological currency to build a comprehensive, verifiable, and rigorously grounded scientific argument.

Data collection was executed through systematic indexing and queries across prominent scientific databases, including Scopus, PubMed, ScienceDirect, and Google Scholar, alongside seminal academic books that serve as foundational references in the history of optics and the philosophy of science. The search strategy employed combinations of Boolean operators and specific keywords, such as "Ibn al-Haytham", "Alhazen", "Islamic optics", "history of optics", "precision medicine", "optical imaging", and etc. The retrieved literature was subsequently screened and selected based on thematic alignment, publication rigor, chronological recency, and its utility in clarifying the conceptual nexus between classical optics and contemporary medical technologies.

Data analysis was conducted through three interconnected phases. The first phase involves historical analysis, which entails identifying the development of Ibn al-Haytham's optical conceptions as detailed across scholarly literature and contextualizing them within the broader evolution of scientific knowledge. The second phase comprises conceptual analysis, which unpacks core notions, such as light, vision, observation, experimentation, scientific validation, and optical representation, to uncover their underlying epistemological architecture. The third phase constitutes a comparative-synthetic analysis, wherein these epistemological principles are juxtaposed with the operational mechanics of optical imaging technologies in modern precision medicine to identify modes of conceptual continuity without positing deterministic causal relationships. Through these integrated phases, this study endeavors to yield an argumentative, critical, and rigorously grounded academic reconstruction that delineates the relevance of Ibn al-Haytham's intellectual legacy to contemporary medical science (Krippendorff 2018).

RESULT AND DISCUSSION

A. The Scientific Foundations of Ibn al-Haytham's Optics

Prior to Ibn al-Haytham, the discourse on optics within classical traditions was predominantly overshadowed by debates that had not entirely extricated themselves from the realm of philosophical speculation. Visual theories developed within the ancient Greek milieu, most notably by Euclid and Ptolemy, tended to rely on the concept of extramission, the presupposition that the eye emits visual rays toward an object to facilitate sight. Within such a framework, light was not yet fully conceptualized as an independent physical phenomenon governed by its own laws of propagation; instead, it was treated primarily as an ancillary element bound to the mechanics of vision. Ibn al-Haytham fundamentally shifted this analytical locus by reframing light and vision as subjects of rigorous scientific inquiry that must be validated through systematic observation and logical deduction (Tbakhi and Amr 2007). Consequently, the scientific foundation of his optics emerged from both a critique of long-standing dogmatic authority and a deliberate effort to construct a more coherent explanation of the interplay between light, the object, and the eye.

The core strength of Ibn al-Haytham's paradigm resides in his empirical demonstration that vision is not a consequence of ocular emission, but rather the result of intromission, light reflecting from an object and entering the eye. He refuted classical theories not merely through dialectical argumentation, but through a structured series of observations and experiments explicitly designed to test the behavior of light under controlled conditions. Contemporary scholarship continues to emphasize that he leveraged phenomena such as the physiological pain experienced when gazing at an intense light source, the occurrence of afterimages, and the absolute absence of vision in total darkness to demonstrate that the eye acts as a passive recipient of external stimuli rather than an active emitter. At this critical juncture, optics transitioned from speculative visual theory into an empirical investigation of how light interacts across spatial domains, media, and the physiological apparatus of sight (Leisten 2015).

Furthermore, Ibn al-Haytham demonstrated that the epistemic validity of optics cannot rest solely on passive observation; it demands the deliberate manipulation of experimental conditions coupled with a rigorous mathematical framework. UNESCO literature characterizes him as a pioneer of modern optics, emphasizing that his scientific approach seamlessly integrated controlled observation, rational analysis, and meticulous empirical testing. In various historical accounts of science, he is celebrated for utilizing the camera obscura (a darkened chamber with a minute aperture) to discern how light propagates rectilinearly and how inverted images are projected onto a surface. This experimental practice is of paramount importance, as it indicates that light was no longer treated as an abstract philosophical ideal, but as a physical phenomenon that could be reproduced, controlled, and quantified. In essence, the bedrock of his optics lies at the convergence of experimentation, geometry, and empirical validation.

From the perspective of the history of science, Ibn al-Haytham's significance extends far beyond the mere correction of visual theories. He established a new epistemic standard for scientific truth: that a claim regarding the natural world cannot attain validity solely by virtue of authoritative transmission, but must instead be subject to reproducible procedures and rational verification. Consequently, Ibn al-Haytham's optics is widely regarded as a pivotal turning point in the transition from the traditions of natural philosophy to a more mature, experimental science. This legacy underscores why contemporary optical science remains deeply indebted to his foundational logic, namely, that genuine knowledge is generated when natural phenomena are purposefully

DOI: 10.5281/zenodo.21331159

interrogated, empirically verified through experimentation, and articulated within a consistent mathematical language.

Aspect	Prior to Ibn al-Haytham	Ibn al-Haytham	Scientific Implications
Visual Theory	Dominated by extramission and highly speculative explanations	Asserted that vision occurs when light from an object enters the eye	Shifted optics from philosophical speculation to a physical-empirical explanation
Mode of Verification	Relied on the dogmatic authority of classical thinkers	Employed controlled observation, rigorous experimentation, and conditional testing	Introduced standardized protocols for scientific proof and verification
Instruments of Understanding	Lacked systematic visual or experimental apparatuses	Utilized the camera obscura and deliberate observations of light behavior	Demonstrated that light could be verified as an objective physical phenomenon
Language of Explanation	Predominantly philosophical and qualitative	Integrated geometric principles with physical analysis	Paved the way for modern mathematical optics
Status of Light	Considered an ancillary element subordinative to the visual process	Framed as an independent subject of scientific inquiry governed by laws of propagation	Recoptualized light as a primary medium of scientific knowledge production

The synthesis provided in the table underscores that Ibn al-Haytham's contribution was not merely a corrective modification of classical theories, but a fundamental restructuring of how light is conceptualized as a physical phenomenon that can be tested, mapped, and explained. Accordingly, the scientific foundation of his optics serves as an epistemological bedrock that enabled optics to evolve into an increasingly mathematical, experimental, and applied discipline in subsequent historical periods.

B. The Paradigm Shift of Light in Modern Science

The paradigm shift regarding light in modern science is characterized by a transition from understanding light merely as a visual phenomenon toward conceptualizing it as an independent physical object governed by its own distinct behaviors, laws, and interactions with matter. Within biomedical literature, light is treated as an analytical component evaluated through the principles of light–matter interactions, including absorption, emission, scattering, and transmission. Recent reviews on the utility of light in diagnosis, therapy, and surgery reaffirm that the foundation of all modern optical applications lies precisely in this fundamental understanding of light–tissue interactions (Krasnikov, Seteikin, and Roth 2019; Yun and Kwok 2017).

Subsequently, light has come to be understood as an informational medium, a vehicle capable of carrying, modulating, and revealing the intrinsic characteristics of biological objects. Modern optical imaging relies on the capacity of light to both illuminate tissue and decode the optical properties of target structures by measuring light propagation within the tissue matrix. In the domains of optical breast imaging and diffuse optical imaging, light is articulated as a mechanism to non-invasively extract structural, functional, metabolic, and molecular data from living tissues (Sarbadhikary, George, and Abrahamse 2022). In other words, light is no longer merely a visual aid, but a scientific information channel that permits the human body to be read as a biological system amenable to quantitative interpretation.

Building upon this trajectory, the role of light has been transformed into a sophisticated clinical instrument operative across diagnosis, therapy, and surgery. Recent reviews in biophotonics indicate that light-based approaches are progressively advancing toward highly precise applications, including label-free imaging techniques, characterization of tissue optical properties, and intraoperative guidance systems for medical interventions. Furthermore, literature underscores that instrumentation in diffuse optical imaging and biomedical optics has integrated into the bedrock of modern scientific infrastructure, enabling the acquisition of biological data with unprecedented resolution, speed, and sensitivity (Angelo et al. 2018; Poplack, Park, and Ferrara 2024).

Collectively, these advancements demonstrate that the paradigm of light in modern science is shifting from visibility toward intelligibility, transitioning from that which is merely seen to that which can be scientifically comprehended. In other words, light transcends its traditional optical utility, transforming into an epistemic medium through which the body, tissues, and biological processes are deconstructed into structured data capable of being analyzed, cross-referenced, and interpreted. At this juncture, the paradigm shift of light bears profound epistemological weight; it underscores that the progress of precision medicine is fundamentally driven by a transformation in how we conceptualize the tripartite relationship between light, the object, and knowledge production.

C. The Convergence with Precision Medicine

The advancement of precision medicine establishes biomedical imaging as a foundational cornerstone for comprehending pathological states at increasingly granular levels, ranging from tissue microstructures and functional dynamics to molecular alterations that elude conventional diagnostic frameworks. Recent literature underscores that advanced imaging technologies have become indispensable to clinical decision-making, significantly refining early detection, therapeutic selection, response monitoring, and precision intervention planning (Evans, Meslin, and Kai 2024; Hricak et al. 2025).

A prominent manifestation of this paradigm is evident in optical coherence tomography (OCT). Recent reviews demonstrate that OCT provides high-resolution, non-invasive, and real-time cross-sectional imaging, rendering it exceptionally valuable in oncology, ophthalmology, and the evaluation of tissues demanding high structural fidelity. In specific clinical scenarios, OCT has evolved toward targeted approaches to enhance diagnostic accuracy and support patient-specific therapeutic pathways. Within this framework, light serves to delineate object surfaces while granting

DOI: 10.5281/zenodo.21331159

access to subsurface microstructures that constitute the essential foundation for precision diagnosis (Esperouz et al. 2025; Mokhtari and Maris 2025; Panzarella et al. 2024).

The nexus between light and precision medicine is equally pronounced in fluorescence imaging, particularly within the near-infrared (NIR) and second near-infrared (NIR-II) spectral windows. Contemporary studies indicate that fluorescence-guided surgery is increasingly pivotal in precision oncology by providing real-time visualization of tumor margins, thereby facilitating intraoperative decisions and improving resection accuracy. Concurrently, NIR-II imaging offers deeper tissue penetration, reduced light scattering, higher spatial resolution, and suppressed autofluorescence backgrounds compared to shorter spectral bands (Cheng et al. 2024; Hsien, Yu, and Chang 2024; Isuri et al. 2025). Consequently, light within this domain has evolved into an empirical tool that guides clinical interventions directly and quantifiably.

Furthermore, Raman spectroscopy exhibits a more nuanced mechanism by decoding the human body as a compilation of molecular “fingerprints”. Several recent reviews affirm that Raman spectroscopy, including surface-enhanced Raman spectroscopy (SERS), holds immense potential in clinical diagnostics and personalized medicine due to its capacity for rapid, sensitive, label-free, and minimally prepared biological sample analysis (Cutshaw et al. 2024; Wang et al. 2024). This underscores that precision medicine relies fundamentally on the capacity of light to map and identify biological variations with high molecular specificity.

An equally vital correlation is found in photoacoustic imaging (PAI) and near-infrared spectroscopy (NIRS)-based approaches. Recent literature highlights that PAI is rapidly approaching clinical translation due to its capacity for deeper, real-time, and multiscale tissue imaging. Meanwhile, NIRS is increasingly adopted as a non-destructive, label-free, and highly sensitive method for diverse diagnostic requirements (Menozzi and Yao 2024). Together, these technologies demonstrate that precision medicine hinges on the ability of light to penetrate, interrogate, and translate biological realities into actionable clinical data.

Collectively, these modalities exhibit a shared paradigm: light functions as an epistemic bridge between invisible biological phenomena and actionable clinical knowledge. At this juncture, the conceptual alignment with Ibn al-Haytham becomes profoundly relevant, not as a claim of linear historical influence, but as an epistemic continuity. Light is conceptualized as an independent medium that must be systematically tested, controlled, and deployed to generate verifiable knowledge. In other words, contemporary precision medicine represents the mature continuation of an optical mode of thought that positions light as a primary instrument for decoding reality.

D. Contributions

The primary contribution of this article lies in its endeavor to reposition Ibn al-Haytham as an intellectual nexus that elucidates the continuity of scientific thought from classical traditions to contemporary medical science. Literature on medical history within the Islamic world indicates that the historiography of medicine possesses profound practical utility in medical education and the cultivation of professional perspectives, far transcending a merely commemorative or retrospective function. Concurrently, scholarship on Islamic scientific heritage affirms that scientific advancement hinges fundamentally on the sustained comprehension of cumulative past achievements (Weber 2023). Within this framework, this re-reading of Ibn al-Haytham offers a broader historical contribution: the history of science transcends a mere inventory of historical figures, serving instead as an analytical conduit to understand how a tradition of knowledge shapes the scientific horizon of subsequent generations.

Philosophically, this article offers an enriched epistemological perspective that conceptualizes knowledge as the product of dynamic interactions among theory, methodology, and scientific apparatuses within an interdisciplinary matrix. Inquiries into epistemology within interdisciplinary research argue that real-world problems demand epistemic frameworks capable of bridging disciplinary boundaries, while critical realism within science education demonstrates that ontology and epistemology can be leveraged to cultivate critical scientific literacy (Boon 2019; Valladares 2021). Furthermore, the literature on epistemic artifacts reveals that scientific models and instruments do not merely mirror reality; rather, they actively configure how reality is represented and understood (Knuuttila 2021). Consequently, this study contributes to the philosophy of science by demonstrating that Ibn al-Haytham’s optics can be interpreted as an epistemic legacy relevant to understanding how scientific instrumentation constructs knowledge rather than merely measuring phenomena.

At the level of biomedical science, this article provides a conceptual contribution by framing precision medicine as a scientific practice heavily reliant on data production, interpretation, and validation. Contemporary literature demonstrates that precision medicine endeavors to replace relative efficacy paradigms with highly personalized therapies through the analysis of large-scale datasets, while other studies assert that data science serves as a vital enabler for personalized medicine (Borck and Lohse 2026). From this standpoint, the contribution of this article does not lie in the formulation of a novel clinical model, but rather in the assertion that optical technologies within precision medicine operate upon an epistemic logic that can be systematically traced historically.

The pedagogical contribution of this article is equally significant. Research in science education indicates that the development of critical thinking, a robust understanding of the nature of science (NOS), and epistemic integrity constitute key elements in constructing dependable scientific literacy (Fikri et al. 2024; Fikri and Munfarida 2023; Fikri and Roqib 2023). Extant studies confirm that critical realism can be utilized as a framework to bridge scientific understanding with critical scientific literacy, while reinforcing epistemic integrity is deemed essential for enabling society to discern and disseminate reliable scientific information. In this context, Ibn al-Haytham provides a highly instructive historical model for science education: he demonstrates that scientific claims must be interrogated rather than passively accepted; that empirzical observation must be accompanied by rigorous methodological reflection; and that the dogmatic authority of knowledge must never supersede empirical demonstration. Therefore, this article is relevant not only to the history of science but also to the design of more critical and reflective science curricula.

CONCLUSION

The overarching findings of this study demonstrate that Ibn al-Haytham’s optics serves as a resilient epistemological foundation for interrogating the scientific architecture of modern precision medicine. This inquiry reinforces that the paradigm shift, wherein

DOI: 10.5281/zenodo.21331159

light transcends its role as a mere visual aid to become an epistemic medium for deciphering biological reality, represents a prolonged conceptual continuity rather than an isolated, contemporary technological leap. Within this matrix, light operates as a foundational instrument for observation, quantification, and scientific representation. Consequently, the nexus between classical optics and precision medicine is most appropriately understood as a structural correspondence of knowledge production continuously evolving across the historiography of science.

Theoretically, this research advances a historiographical approach to the history of science that eschews the naive hagiography of historical figures, advancing instead toward the identification of enduring epistemic logics that remain operational within contemporary science. This article also contributes to the philosophy of science by demonstrating that the relationships among theory, methodology, and instrumentation are inextricably linked; optical instruments do not merely record data but actively configure how biological reality is epistemically apprehended and validated. Practically, this study offers valuable implications for science education, the philosophy of science, and modern medical training, particularly by fostering a more reflexive understanding of optical imaging technologies as historical artifacts of human scientific rationality rather than merely neutral, value-free technical apparatuses.

Nevertheless, this study is bounded by certain limitations; its reliance on qualitative desk-based documentation and historical-epistemological analysis precludes an empirical technical evaluation or clinical validation of specific optical modalities. Furthermore, the scope of the literature reviewed predominantly emphasizes the conceptual synthesis between classical Islamic optics and precision medicine, leaving a broader comparative mapping of alternative classical optical manuscripts for future inquiry. Accordingly, future research should expand the corpus of primary and secondary sources, deepen the critical engagement with specific optical modalities, such as OCT, fluorescence imaging, Raman spectroscopy, and photoacoustic imaging, and formulate more operational analytical frameworks capable of bridging the history of science, the philosophy of knowledge, and light-based biomedical innovations.

REFERENCES

1. Adlini, Miza Nina, Anisya Hanifa Dinda, Sarah Yulinda, Octavia Chotimah, and Sauda Julia Merliyana. 2022. “Metode Penelitian Kualitatif Studi Pustaka.” *Edumaspul Jurnal Pendidikan* 6(1). doi: 10.33487/edumaspul.v6i1.3394.

2. Angelo, Joseph P., Sez-Jade Chen, Marien Ochoa, Ulas Sunar, Sylvain Gioux, and Xavier Intes. 2018. “Review of Structured Light in Diffuse Optical Imaging.” *Journal of Biomedical Optics* 24(7):1–21. doi: 10.1117/1.JBO.24.7.071602.

3. Bec, Krzysztof B., Justyna Grabska, and Christian W. Huck. 2020. “Near-Infrared Spectroscopy in Bio-Applications.” *Molecules* 25:1–36.

4. Boon, Mieke. 2019. “Epistemology for Interdisciplinary Research – Shifting Philosophical Paradigms of Science.” *European Journal for Philosophy of Science* 9:1–28.

5. Borck, Cornelius, and Simon Lohse. 2026. “Sorting Out and Navigating Uncertainty in Precision Medicine.” *History and Philosophy of the Life Sciences* 48:1–21.

6. Cheng, Han, Hongtao Xu, Boyang Peng, Xiaojuan Huang, Yongjie Hu, Chongyang Zheng, and Zhiyuan Zhang. 2024. “Illuminating the Future of Precision Cancer Surgery with Fl Uorescence Imaging and Arti Fi Cial Intelligence Convergence.” *Npj Precision Oncology*. doi: 10.1038/s41698-024-00699-3.

7. Cutshaw, Gabriel, Saji Uthaman, Nora Hassan, Siddhant Kothadiya, Xiaona Wen, and Rizia Bardhan. 2024. “The Emerging Role of Raman Spectroscopy as an Omics Approach for Metabolic Profiling and Biomarker Detection towards Precision Medicine.” *HHS Public Access* 123(13):8297–8346. doi: 10.1021/acs.chemrev.2c00897.The.

8. Esperouz, Fariba, Domenico Ciavarella, Mauro Lorusso, and Lucio Lo Russo. 2025. “Critical Review of OCT in Clinical Practice for the Assessment of Oral Lesions.” *Frontiers in Oncology* 1–9. doi: 10.3389/fonc.2025.1569197.

9. Evans, William, Eric M. Meslin, and Joe Kai. 2024. “Precision Medicine — Are We There Yet? A Narrative Review of Precision Medicine’s Applicability in Primary Care Precision Medicine.” *Journal of Personalized Medicine* 14:1–17.

10. Fikri, Muslim, and Elya Munfarida. 2023. “Konstruksi Berpikir Kritis Dalam Pendidikan Islam: Analisis Tafsir Maudhu’i Berdasarkan Al-Qur’an.” 8(1):108–20. doi: 10.25299/al-thariqah.2023.vol8(1).11469.

11. Fikri, Muslim, Farid Prihandoyo, M. Misbah, and Masyarakat Islam. 2024. “Pendidikan Qur’ani: Konsep Pembudayaan Al-Qur’an Dan Penerapannya Dalam Pengembangan Masyarakat Islam.” *Jurnal Review Pendidikan Dan Pengajaran (JRPP)* 7:10965–75.

12. Fikri, Muslim, and Moh Roqib. 2023. “Menggali Kearifan Lokal Nusantara Melalui Integrasi Islam, Sains, Dan Budaya: Perspektif Historis Era Walisongo.” *Al-Isyraq: Jurnal Bimbingan, Penyuluhan, Dan Konseling Islam* 6(3):673–90.

13. Fujimoto, James G., Costas Pitris, Stephen A. Boppart, and Mark E. Brezinski. 2000. “Optical Coherence Tomography: An Emerging Technology for Biomedical Imaging and Optical Biopsy.” *Neoplasia* 2(1–2):9–25.

14. Ghasemi, Mojtaba, Iraj Nabipour, Abdolmajid Omrani, Zeinab Alipour, and Majid Assadi. 2016. “Precision Medicine and Molecular Imaging: New Targeted Approaches Toward Cancer Therapeutic and Diagnosis.” *Am J Nucl Med Mol Imaging* 6(6):310–27.

15. Hricak, Hedvig, Marius E. Mayerhoefer, Ken Herrmann, Jason S. Lewis, Martin G. Pomper, Christopher P. Hess, Katrine Riklund, and Andrew M. Scott. 2025. “Advances and Challenges in Precision Imaging.” *HHS Public Access* 26(1):1–22. doi: 10.1016/S1470-2045(24)00395-4.Advances.

16. Hsien, Ming, Chan Yu, and Chan Chang. 2024. “Recent

DOI: 10.5281/zenodo.21331159

Advances in near - Infrared I / II Persistent Luminescent Nanoparticles for Biosensing and Bioimaging in Cancer Analysis." *Analytical and Bioanalytical Chemistry* 416(17):3887–3905. doi: 10.1007/s00216-024-05267-z.

17. Isuri, Ritesh K., Justin Williams, David Rioux, Paul Dorval, Pierre-alix Dancer, and Edward J. Delikatny. 2025. "Clinical Integration of NIR-II Fluorescence Imaging for Cancer Surgery: A Translational Evaluation of Preclinical and Intraoperative Systems." *Cancers* 1–22.
18. Khristoforova, Yulia, Lyudmila Bratchenko, and Ivan Bratchenko. 2023. "Raman-Based Techniques in Medical Applications for Diagnostic Tasks: A Review." *International Journal of Molecular Sciences* 24:1–23.
19. Knuuttila, Tarja. 2021. "Epistemic Artifacts and the Modal Dimension of Modeling." *European Journal for Philosophy of Science* 11:1–18. doi: 10.1007/s13194-021-00374-5.
20. Krasnikov, Ilya, Alexey Seteikin, and Bernhard Roth. 2019. "Advances in the Simulation of Light – Tissue Interactions in Biomedical Engineering." *Biomedical Engineering Letters* 9(3):327–37. doi: 10.1007/s13534-019-00123-x.
21. Krippendorff, Klaus. 2018. *Content Analysis: An Introduction to Its Methodology*. 4th ed. California: SAGE Publication.
22. Leisten, Thomas. 2015. "Ibn Al-Haytham on Optics and the Human Eye." *Aspetar: Sports Medicine Journal* 202–7.
23. Menozzi, Luca, and Junjie Yao. 2024. "Deep Tissue Photoacoustic Imaging with Light and Sound." *Npj Imaging* 1–12. doi: 10.1038/s44303-024-00048-w.
24. Moghadam, Sanam Daneshpour, Bogdan Maris, Ali Mokhtari, Claudia Daffara, and Paolo Fiorini. 2025. "OCT in Oncology and Precision Medicine: From Nanoparticles to Advanced Technologies and AI." *Bioengineering* 12:1–23.
25. Mokhtari, Ali, and Bogdan Mihai Maris. 2025. "A Survey on Optical Coherence Tomography — Technology and Application." *Bioengineering* 12:1–24.
26. Panzarella, Vera, Fortunato Buttacavoli, Vito Rodolico, Laura Maniscalco, Alberto Firenze, Viviana De Caro, Rodolfo Mauceri, Simona E. Rombo, and Giuseppina Campisi. 2024. "Application of Targeted Optical Coherence Tomography in Oral Cancer: A Cross-Sectional Preliminary Study." *Diagnostics* 1–14.
27. Poplack, Steven P., Eun-yeong Park, and Katherine W. Ferrara. 2024. "Optical Breast Imaging: A Review of Physical Principles, Technologies, and Clinical Applications." *HHS Public Access* 5(5):520–37. doi: 10.1093/jbi/wbad057.Optical.
28. Rehman, Muhammad Farhan Ur, Muhammad Raghib Hussain, Ayaz Akhter, Zumara Iqbal, Tahreem, and Farah Sadique. 2021. "Contemporary Significance Of Ibn Al- Haytham ' s (Alhazen) Inventions And Theoretical Contributions." *Ilkogretim Online* 20(1):391–95. doi: 10.17051/ilkonline.2021.06.040.
29. Riksen, Jonas J. M., Anton V. Nikolaev, and Gijs van Soest. 2023. "Photoacoustic Imaging on Its Way Toward Clinical Utility: A Tutorial Review Focusing on Practical Application in Medicine." *Journal of Biomedical Optics* 28(12):1–40. doi: 10.1117/1.JBO.28.12.121205.
30. Sabra, Abdulhamid I., and Jan P. Hogendijk. 2023. *The Optics of Ibn Al-Haytham*. London: Warburg Institute.
31. Sarbadhikary, Paromita, Blassan P. George, and Heidi Abrahamse. 2022. "Theranostics Paradigm Shift in Future Biophotonics for Imaging and Therapy: Miniature Living Lasers to Cellular Scale Optoelectronics." *Theranostics* 12(17):7335–50. doi: 10.7150/thno.75905.
32. Schouw, H. M., L. A. Huisman, Y. F. Janssen, R. H. J. A. Slart, R. J. H. Borra, A. T. M. Willemsen, A. H. Brouwers, J. M. van Dijl, R. A. Dierckx, G. M. van Dam, W. Szymanski, H. H. Boersma, and S. Kruijff. 2021. "Targeted Optical Fluorescence Imaging: A Meta-Narrative Review and Future Perspectives." *European Journal of Nuclear Medicine and Molecular Imaging* 48:4272–92. doi: 10.1007/s00259-021-05504-y.
33. Sedgwick, H. A. 2022. "Ibn Al-Haytham's Ground Theory of Distance Perception." *I-Perception* 13(5):1–18. doi: 10.1177/20416695221118388.
34. Tbakhi, Abdelghani, and Samir S. Amr. 2007. "Ibn Al-Haytham: Father of Modern Optics." *Arab and Muslim Physicians and Scholars* 27(6):464–67.
35. Valladares, Liliana. 2021. "Scientific Literacy and Social Transformation." *Science & Education* 30:557–87. doi: 10.1007/s11191-021-00205-2.
36. Wang, Yumei, Liuru Fang, Yuhua Wang, and Zuzhao Xiong. 2024. "Current Trends of Raman Spectroscopy in Clinic Settings: Opportunities and Challenges." *Advanced Science* 1–36. doi: 10.1002/advs.202300668.
37. Weber, Alan S. 2023. "Clinical Applications of the History of Medicine in Muslim-Majority Nations." *Journal of History of Medicine and Allied Sciences* 78:46–61.
38. Yun, Seok Hyun, and Sheldon J. J. Kwok. 2017. "Light in Diagnosis, Therapy, and Surgery." *HHS Public Access* 1:1–39. doi: 10.1038/s41551-016-0008.Light.

DOI: 10.5281/zenodo.21331159