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Barriers to Intellectual Property and Directions of Evolution of Imaging Techniques – Past, Present and Future

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ABSTRACT

The past 20 years have witnessed a rapid evolution of imaging techniques. Several factors, including technological advances, the growing importance of data, and the increasing demand for new and innovative imaging applications, have driven this evolution. One of the key drivers of the evolution of imaging techniques has been technological advances. For example, the development of new sensor technologies, such as charge-coupled devices (CCDs) and complementary metal-oxide-semiconductor (CMOS) sensors, has led to significant improvements in image quality. In addition, the development of new imaging modalities, such as magnetic resonance imaging (MRI) and computed tomography (CT), has expanded the range of imaging applications. Despite the many benefits of the evolution of imaging techniques, several challenges need to be addressed. One challenge is the increasing complexity of imaging techniques. As imaging techniques become more complex, they become more challenging to develop and use. In addition, the growing complexity of imaging techniques can lead to increased costs. Another challenge is the growing importance of intellectual property (IP). IP rights can protect the developers of imaging techniques from unauthorised copying and use. However, IP rights can also create barriers to innovation, making it difficult for new companies to enter the market. The future of imaging techniques is bright. As technological advances continue, imaging techniques will become more powerful and versatile. In addition, as the demand for new and innovative imaging applications continues to grow, imaging techniques will evolve to meet these needs.

1. Introduction

Medical imaging has significantly evolved in recent decades, and advancements in image sensors have played a crucial role in this transformation. Charge-coupled device (CCD) and Complementary Metal-Oxide-Semiconductor (CMOS) techniques [1], [2] have significantly contributed to improving the quality of images obtained, which has a significant impact on diagnosis, treatment, and patient quality of life [3]. These instrumental and methodological advancements enhance diagnostic capabilities and deepen our understanding of various pathologies [4].

Benefits of Using CCD and CMOS in Medical Imaging: Improved resolution: Allows visualisation of fine anatomical details, essential for early diagnosis of diseases. Superior contrast: Facilitates the identification of anomalies and differentiation between similar anatomical structures. Increased clarity: Provides more precise images, providing a more accurate interpretation of diagnostic information [5]. Detailed information: Advanced imaging techniques can provide information about the function and metabolism of the body, aiding in the diagnosis of complex diseases [6], [7].

Substantial research and innovation investments safeguarded by patents, trademarks, and other forms of intellectual property have enabled the development and refinement of CCD and CMOS techniques [3], [8].
CCD and CMOS techniques have revolutionised medical imaging, provided more accurate diagnoses and improved patient quality of life. Intellectual property protection is crucial in stimulating innovation and accelerating progress in this vital field [8].

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2. Literature review

Imaging techniques have evolved remarkably in recent years, becoming essential tools in various fields and significantly contributing to the medical field. Medical imaging allows for the detailed visualisation of the internal structures of the human body, providing valuable information for the diagnosis, monitoring, and treatment of various diseases [6], [7].

The continuous evolution of imaging techniques has fundamentally reshaped the medical landscape, enabling more timely and accurate diagnoses, optimising therapeutic interventions, and ultimately enhancing patient outcomes. Further advancements in this domain are anticipated to hold significant potential for the future of medicine [6]. This evolution spans from analogue two-dimensional methods to advanced digital three-dimensional techniques, improving diagnostic precision and informing treatment strategies [9].

Ongoing research and development in sensor technology continue to drive improvements in image quality, sensitivity, and dynamic range, promising further advancements in medical imaging [6]. The advancements in CCD and CMOS sensor technology have revolutionised the field of medical imaging, leading to enhanced diagnostic capabilities [10], improved patient outcomes, and broader applications in various medical disciplines. Continued advancements in this field hold great promise for the future of medical diagnostics and treatment [11].

3. Methodology

Significant Benefits of Imaging Techniques in Medicine

Medical imaging techniques have experienced substantial advancements in recent years, primarily propelled by innovations in image sensor technology [12]. Specifically, Charge-Coupled Device and Complementary Metal-Oxide-Semiconductor sensors have been instrumental in this progression, facilitating the acquisition of progressively higher-fidelity images [3], [13], [14]. These technological improvements have culminated in heightened diagnostic accuracy, optimised therapeutic strategies, and improved patient surveillance across diverse clinical specialities [6], [15], [16].

Charge-coupled Devices and Complementary metal-oxide-sensor devices serve as foundational technologies in contemporary medical imaging instrumentation. They detect and convert incident photons into quantifiable digital signals to facilitate image reconstruction [17], [18].

CCD and CMOS sensors have significantly improved image resolution, contrast, and noise levels, leading to more accurate and informative diagnostic images. The improved image quality provided by these sensors has enhanced clinicians' ability to detect and diagnose diseases at earlier stages, leading to better patient outcomes [19], [20].

CCD and CMOS sensors are used in various medical imaging modalities, including radiography, ultrasound, MRI, and CT, enabling advancements across different medical disciplines [12].

CCD Sensors Features: High light sensitivity: Ideal for low-light photography, capturing accurate images in challenging lighting conditions. High resolution: Delivers detailed images with sharp edges and minimal noise, enabling precise visualisation of delicate structures. Accurate grayscale reproduction: Ensures faithful representation of reality, providing clinicians with reliable information for diagnostic purposes [21], [22].

Working Principles comprise photosensitive cells, typically arranged in a rectangular pattern. Each photosensitive cell acts as a miniature capacitor, capable of storing an electric charge. When light strikes a photosensitive cell, it generates an electric charge proportional to the light intensity [23].

During the readout process to capture an image, electric charges from the photosensitive cells are transferred, row by row, to an amplifier. The amplifier converts the electric charges into voltage signals, which are then digitised and stored as an image [24]. This sequential transfer and conversion process ensures high fidelity in image acquisition, which is crucial for diagnostic accuracy in medical applications [13].

CMOS Sensors Features: Low power consumption: Ideal for portable devices, allowing for extended battery life and efficient operation. High speed: Capable of capturing fast-moving images with minimal motion blur, enabling dynamic imaging and video recording applications. Cost-effective: Lower manufacturing costs compared to CCD sensors, contributing to the affordability of imaging devices and expanding access to diagnostic technologies [25].

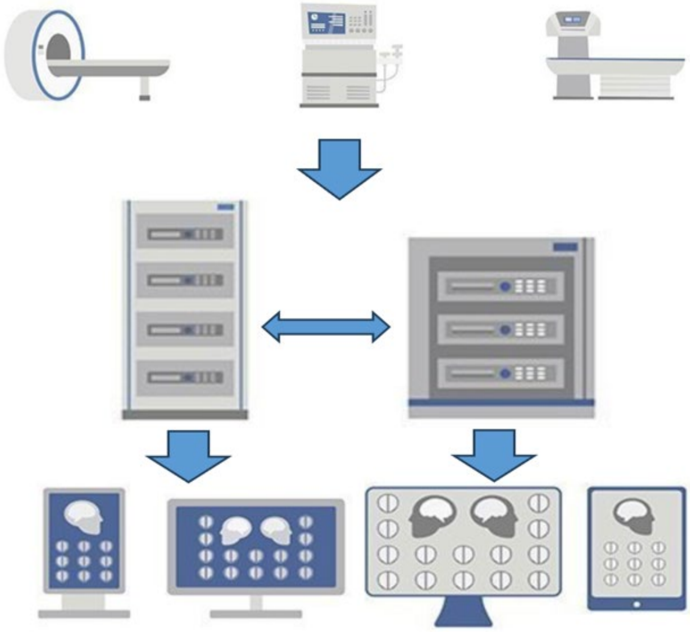

Figure 1. Schematic of making and transmitting radiological images through the PACS system.
Source: Authors' own contribution

Working Principle: Composed of an array of phototransistors, typically arranged in a rectangular pattern. Each phototransistor is a semiconductor device that amplifies the incident light's electrical signal. Amplification of the signal at each pixel enhances the image's signal-to-noise ratio, resulting in improved image quality [26].

Readout Process: To capture an image, the electrical signals generated by the phototransistors are amplified and converted into digital signals. These digital signals are then stored as an image file, allowing easy storage, sharing, and analysis [27].

Advantages: High image quality with excellent resolution, contrast, and dynamic range. Low noise levels, resulting in clear and sharp images [28]. Compact and lightweight design, enabling integration into various medical imaging devices. High speed and efficiency make them suitable for real-time imaging and video applications [29], [30]. With their integrated circuitry, CMOS sensors offer individual pixel-level amplification and analogue-to-digital conversion, further enhancing their utility in complex medical imaging systems [31], [32].

CMOS sensors offer a compelling combination of high performance, low power consumption, and cost-effectiveness, making them a key technology in modern medical imaging. Their continued development and refinement hold great promise for the future of diagnostic accuracy, patient care, and the accessibility of imaging technologies [20].

Image Quality and Sensor Selection

Crucial Considerations: The choice of the appropriate sensor depends on the specific application and its requirements. High-quality photography in low-light conditions benefits from CCD sensors' high sensitivity and accurate grayscale reproduction. Portable devices and applications involving fast-moving images favour CMOS sensors' low power consumption, high speed, and cost-effectiveness [33]. Conversely, CMOS sensors integrate transistors within each pixel for charge amplification and transfer, enabling greater integration and lower power consumption than CCDs [34], [35].

Advancements in Medical Imaging: Regardless of the sensor type, both CCD and CMOS technologies have significantly enhanced image quality in the medical field. This evolution has dramatically improved diagnostic accuracy, optimised treatment strategies, and ultimately enhanced patient quality of life [7]. Further technological innovations are pushing towards even higher resolutions, faster capture speeds, and greater light sensitivity in CMOS sensors, promising advancements in medical imaging [36], [37].

Key Benefits: Improved image resolution, contrast, and dynamic range provide clinicians with more detailed and precise information for accurate diagnosis. Reduced image noise levels enhance clarity and sharpness, facilitating the identification of subtle abnormalities and aiding in early disease detection. Increased availability of high-quality imaging technologies expands access to diagnostic services and improves healthcare outcomes for patients across diverse populations [38], [39].

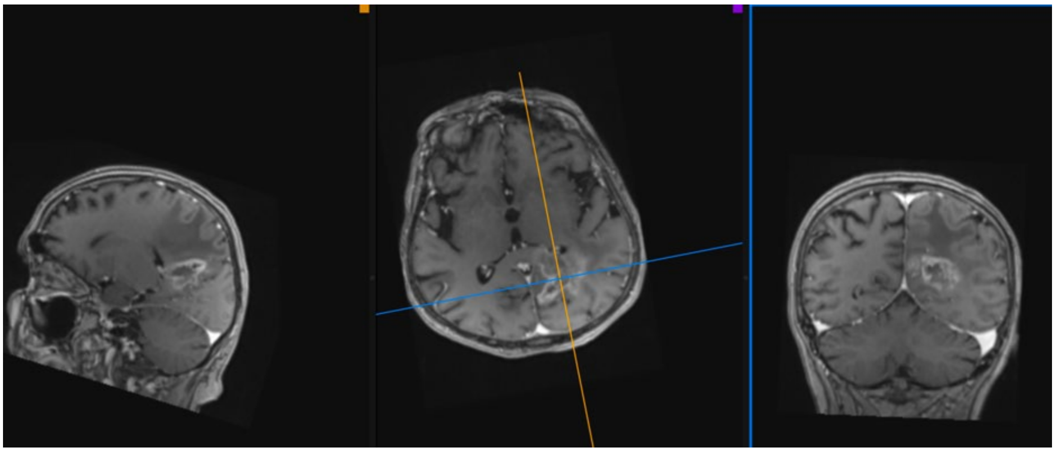

Figure 2. Images obtained by Magnetic Resonance were transmitted through the PACS system of a patient with a brain injury.
Source: Authors' own contribution

The ongoing technological evolution of CCD and CMOS sensor technologies, in conjunction with their innovative applications in medical imaging, offers substantial prospects for the future of medicine. By enabling the generation of high-fidelity visual data, these technologies empower clinicians to make informed decisions, deliver personalised care, and ultimately enhance patient outcomes [10], [40].

Technological Advancements Leading to Improved CCDs

The advancements in CCD technology that have benefitted radiological imaging are driven by several technological improvements: Increased Pixel Density: Modern CCDs feature higher pixel densities, translating into ultra-high-resolution images. This improvement is vital for diagnostic applications, where every detail can have diagnostic significance [3]. Enhanced Sensitivity: CCDs continue to become more sensitive, especially in low-light conditions. This sensitivity is essential for radiology, where noise in a less sensitive detector can obscure subtle differences in tissue. Reduction in Power Consumption: Newer CCDs are designed to consume less power, reduce operational costs, and support more sustainable medical technology infrastructures [78]. Integration with CMOS Technology: While traditionally distinct, incorporating aspects of CMOS technology into CCDs has resulted in sensors that combine the best features of both technologies, offering enhanced speed, flexibility, and image quality [25].

As technology continues to evolve, the future holds even greater potential for CCDs to expand the capabilities of radiological imaging. Continued research and development efforts will likely integrate CCDs into various diagnostic applications, potentially incorporating advanced computational techniques such as machine learning for real-time image analysis and interpretation [79].

CCD technology represents a substantial advance in modern radiological imaging evaluations. Its continued development and integration are set to improve diagnostic practices and enhance overall patient care, making it a cornerstone of future advancements in medical imaging technology [6].

Precise Diagnosis

Enhanced Accuracy and Early Detection: Medical imaging facilitates the precise identification of lesions, tumours, malformations, and other anatomical abnormalities, contributing to early and accurate diagnosis. Advancements in image sensors have led to a significant increase in the quality of medical images. CCD and CMOS technologies enable the acquisition of images with higher resolution, improved contrast, and enhanced clarity, significantly impacting diagnostic precision [7].

Visualisation of Fine Anatomical Details: Increased resolution allows for visualising fine anatomical details that might be obscured in lower-quality images. This enables clinicians to detect subtle abnormalities indicative of early disease or other medical conditions [41]. Such enhancements are pivotal for applications like endoscopy, where ultra-high-definition imaging provides critical insights into mucosal details and surface vasculature, significantly aiding clinical diagnosis [42].

Improved Anomaly Detection: Better contrast and enhanced clarity facilitate the identification of anomalies, contributing to earlier diagnosis and improved patient outcomes. Subtle tissue texture, density, or vascularisation changes can be more easily detected, leading to more accurate and timely diagnoses [43].

Detailed Information for Differential Diagnosis: Advanced imaging techniques can provide detailed information about the body's function and metabolism [6]. This information can be used to differentiate between similar conditions, aiding in the diagnostic process and ensuring appropriate treatment [44].

Key Benefits: Improved diagnostic accuracy leads to better patient outcomes and reduced healthcare costs. Early detection of diseases allows for timely intervention and treatment, improving the chances of successful outcomes [45]. Access to high-quality imaging technologies, essential for accurate diagnosis and treatment planning across various diseases, notably improves healthcare equity and enhances patient care [6], [46]. By enabling accurate diagnosis and guiding appropriate treatment, imaging diagnostics lead to optimal patient outcomes [47]. This is particularly critical in regions with limited resources, such as low- and middle-income countries, where increased access to medical imaging can significantly reduce mortality and achieve lasting patient benefits [46], [48]. Diagnostic imaging is recognized as a fundamental component of effective primary care [49], and improving its accessibility helps mitigate existing worldwide inequalities in radiological services [49]. Addressing disparities in access, particularly those influenced by socioeconomic factors and geography, is crucial for achieving health equity, ensuring all individuals have fair opportunities for optimal health [50], [51], [52], [53].

The advancements in image sensor technology and innovative medical imaging applications have revolutionised diagnostics. By providing high-quality images and detailed information, these technologies empower clinicians to make informed decisions, deliver personalised care, and improve patient outcomes [6].

Intellectual Property (IP) Challenges in Radiology and Medical Imaging

The rapid advancement of medical imaging techniques has given rise to a few intellectual property (IP) challenges. The complexity and high costs of patenting, the unclear boundaries of copyright protection, and the risk of disclosing trade secrets can significantly impact innovation and access to advanced imaging technologies [54].

Key Challenges: Patenting: The complex and expensive nature of the patenting process can hinder innovation, particularly for small and medium-sized enterprises (SMEs) and academic institutions [55]. *Copyright Protection:* The unclear boundaries of copyright protection for medical images can lead to disputes and uncertainty regarding ownership and usage rights. *Trade Secrets:* The risk of disclosing trade secrets through publications or presentations can discourage innovation and limit sharing knowledge and expertise [56].

Impact on Innovation: IP challenges can create barriers to entry for new entrants, hindering competition and slowing down the pace of innovation. The high costs of patenting and licensing can limit the availability of resources for research and development [57]. Moreover, the proprietary nature of specific imaging algorithms and software, often protected by intellectual property, can impede interoperability and data sharing among healthcare systems, fragmenting patient care pathways and hindering collaborative research efforts. This fragmentation exacerbates challenges in establishing universal health coverage and perpetuates health disparities, particularly in regions with limited access to advanced diagnostic tools [46].
The uncertainty surrounding IP rights can discourage collaboration and knowledge sharing among researchers and clinicians [58].

Impact on Access to Technology: IP challenges can limit the availability of advanced imaging technologies in low-resource settings. High licensing fees and restrictive patent terms can make it difficult for healthcare providers to adopt new technologies. The lack of clarity regarding IP rights can impede the development of open-source software and tools for medical imaging [58].

Addressing IP challenges in medical imaging requires a multi-pronged approach that includes streamlining the patenting process and reducing the associated costs, clarifying the boundaries of copyright protection for medical images, promoting open-source software and tools, and fostering collaboration and knowledge sharing among researchers and clinicians [59]. Such efforts are critical for promoting an environment where innovation thrives while ensuring equitable access to cutting-edge diagnostic tools, particularly for populations most impacted by health disparities [60].

By actively addressing these pervasive intellectual property challenges—which currently hinder innovation, fragment patient care pathways, and perpetuate health disparities—we can create an environment that genuinely fosters innovation and ensures equitable global access to advanced medical imaging technologies, thereby significantly improving patient outcomes worldwide.

Impact of IP Barriers

High Costs: Patenting inventions in the imaging field involves significant costs, limiting access to innovation for small companies and research centres [59]. These financial burdens can deter entities from pursuing intellectual property protection, which may, in turn, stifle further innovation or impede the widespread adoption of beneficial technologies [59]. Patent application, examination, and maintenance fees can be prohibitive for entities with limited resources [61]. High costs can limit investments in research and development, affecting progress in medical imaging.

Complexity: The patent application process is complex and lengthy, which can delay the implementation of new imaging techniques. Patentability requirements, such as novelty, inventiveness, and industrial applicability, can be challenging to meet for inventions in the imaging field [54]. This complexity is compounded by the rapid evolution of medical imaging technologies, making it difficult for patent offices to keep pace with cutting-edge developments and for applicants to accurately define their claims [62]. The lengthy patent process can delay the commercialisation of inventions and the recovery of investments.

Unclear Boundaries: Copyright can be difficult to apply in the imaging field, as there are uncertainties regarding the protection of software algorithms, image databases, and other elements. Lack of legal clarity can lead to litigation and discourage innovation in the imaging field. Identifying the copyright holder can complicate licensing and legal use of protected materials [60].

Trade Secrets: Using trade secrets can limit collaboration between researchers and the medical industry, affecting progress in the field. The fear of disclosing confidential information can discourage the exchange of knowledge and expertise [63]. This reluctance can hinder the development of standardised protocols and shared resources, essential for advancing medical imaging technology and its applications [64].

Principles of IP protection in Medical Imaging

Intellectual Property (IP) is critical to driving innovation and technological progress in medical imaging. IP protection incentivises researchers and companies to invest in developing new imaging technologies and techniques [62]. This protection also ensures that creators can reap the economic benefits of their innovations, fostering a sustainable ecosystem for continued advancements. The robust protection of intellectual property rights, encompassing patents, copyrights, and trade secrets, ensures that the significant investments in research and development within medical imaging are safeguarded, thereby encouraging further innovation [65].

A strong IP protection should have:

Encourages research and development: IP provides a legal framework for protecting inventions, enabling researchers and companies to invest in developing new imaging technologies. This leads to developing new diagnostic tools and treatments that can improve patient outcomes [66], [67].

Facilitates technology transfer: IP protection can facilitate technology transfer between stakeholders, such as universities, research institutes, and companies. This can accelerate the development and adoption of new imaging technologies [68].

Promotes competition: IP protection can encourage competition in the market for imaging technologies, leading to lower prices and improved patient quality.

Overall, IP protection plays a vital role in ensuring the continued advancement of medical imaging technologies and improving the quality of patient care by fostering innovation, enabling the translation of research into clinical practice, and facilitating investment in new diagnostic and therapeutic solutions [62], [65], [67], [69], [70]. However, the current IP landscape also presents significant challenges that can impede equitable access and slow scientific progress in medical imaging, necessitating a careful balance between protection and public benefit [71].

Principles of IP Protection in Medical Imaging are established through National and International legislation, including:

Law no. 84/1998 on Patents for Inventions: Protects new, inventive, and industrially applicable inventions, including devices, methods, and materials used in medical imaging.

Law no. 60/1990 on the Protection of Topographies of Integrated Circuits: Protects the layout design of integrated circuits used in CCD and CMOS image sensors.

Law no. 129/1992 on the Protection of Industrial Designs: Protects the aesthetic appearance of medical imaging devices.

Paris Convention for the Protection of Industrial Property: Establishes fundamental principles for protecting patents, industrial designs, trademarks, and geographical indications.

The TRIPS Agreement (Trade-Related Aspects of Intellectual Property Rights) includes specific rules on IP protection applicable to international trade.

4. Results and discussion

Due to a lack of transparency, Intellectual Property Protection's essential role in advancing medical imaging can limit access to innovation and hinder the development of interoperable solutions [55].

IP barriers can significantly impact innovation and access to advanced imaging technologies. Addressing these barriers requires a few measures, including simplifying the patent application process and reducing associated costs, clarifying copyright legislation in the imaging field, promoting open licenses and interoperable standards, and facilitating collaboration between researchers and the medical industry.

The development and refinement of CCD and CMOS sensors have been driven by significant investments in research and innovation, protected by patents, trademarks, and other intellectual property (IP) tools. IP protection plays a critical role in stimulating progress in the field of medical imaging [72] by:

Stimulating Innovation: It provides companies and inventors with a legal framework to commercialise their inventions and recoup their investments. This encourages risk-taking and the allocation of resources towards the research and development of new imaging techniques and devices [68].

Facilitating Technology Transfer: IP protection enables companies and universities to collaborate confidently, ensuring knowledge and expertise sharing. This accelerates the diffusion of innovations and contributes to the overall advancement of the field [67].

Promoting Competition: IP protection provides a competitive environment, encouraging new companies and innovative products to enter. Patients benefit from a broader range of diagnostic and treatment options at competitive prices [73].

CCD and CMOS technologies have revolutionised medical imaging, impacting diagnosis, treatment, and patient quality of life. IP protection has played a vital role in facilitating this progress, stimulating innovation, and accelerating technology transfer [74]. However, while fostering innovation, the intricate interplay of intellectual property rights also introduces complexities, particularly concerning accessibility and the potential for monopolistic practices within the highly specialised medical imaging market [75].

Improved Image Quality: CCD and CMOS sensors offer significantly better resolution and clarity, enabling more accurate diagnosis of diseases.

Early Detection of Diseases: Advanced imaging techniques allow for identifying diseases in their early stages, increasing the chances of successful treatment.

Development of New Medical Procedures: Advanced medical imaging facilitates the development of new minimally invasive and more efficient procedures.

Increased Access to Diagnosis: CCD and CMOS technologies are more affordable and easier to use, allowing for better diagnostic accessibility for patients in rural or underserved areas.

Intellectual property protection is a fundamental pillar of progress in medical imaging. By stimulating innovation, facilitating technology transfer, and promoting competition, IP improves the quality of diagnosis and treatment, significantly impacting patients' quality of life [54], [62]. Despite these advancements, it is essential to consider the ethical and accessibility implications of these proprietary technologies to ensure equitable distribution and affordability of advanced medical imaging diagnostics [67].

5. Conclusions

Integrating Charge-Coupled Device technology into radiological imaging systems marks a significant advancement in medical diagnostics. The progression of CCD technology has led to enhanced image quality, reduced radiation exposure, and improved operational efficiency. These benefits collectively enhance diagnostic accuracy, patient safety, and healthcare delivery.

Charge-coupled devices (CCDs) are sophisticated imaging sensors primarily known for their pivotal role in digital photography and astronomy. Recently, the radiological imaging field has seen significant advancements with the introduction and integration of CCD technology. This technological leap has enhanced imaging capabilities, improving diagnostic precision and overall healthcare outcomes.

Enhanced Image Quality: The high quantum efficiency of CCDs ensures that more incoming photons are converted into image information, leading to superior image resolution and detail. This attribute is crucial for radiological imaging, where detecting minute tissue density or structure variations can significantly impact diagnoses. This enhanced clarity aids in the precise identification of pathologies such as subtle tumours or intricate vascular abnormalities [76].

Reduced Radiation Exposure: CCDs can produce high-quality images with lower radiation doses than traditional film-based or older digital systems. This reduction is particularly beneficial in pediatric imaging and frequent diagnostic procedures, emphasising patient safety and long-term health [77].

Improved Diagnostic Accuracy: The clarity and detail provided by CCD-facilitated images allow radiologists to identify subtle pathologies more confidently and accurately. The improved imaging can lead to earlier detection of diseases, such as tumours or vascular anomalies, providing patients with a broader range of treatment options.

Efficient Data Handling: CCDs generate digital images that are easily stored, transmitted, and retrieved, significantly improving workflow and patient throughput. This digital transition is crucial for integrated electronic health record systems, allowing for the seamless incorporation of medical imaging data alongside textual information, enhancing diagnostic precision and treatment efficacy. The digital nature of these images facilitates robust interoperability and standardised data exchange across diverse healthcare platforms, supported by established protocols such as DICOM, which are essential for effective information sharing between institutions. Furthermore, this capability enhances collaborative diagnostic practices, enabling specialists to remotely access, analyse, and discuss cases, which is particularly beneficial in telepathology and multi-disciplinary consultations.

Versatile Applications: Besides traditional X-ray imaging, CCD technology is advancing other forms of radiological evaluations, including mammography, heavy ion Computed Tomography, and fluorescence imaging. Its use in Near-Infrared and Shortwave Infrared fluorescence imaging systems and bioluminescence imaging demonstrates its critical role in determining detection limitations and enhancing diagnostic capabilities. This adaptability to various radiographic modalities and optical tomography systems highlights its potential to revolutionise multiple diagnostic fields.

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