Dose Archiving and Communication System in Moroccan Healthcare: A Unified Approach to X-Ray Dose Management and Analysis

Lhoucine Ben Youssef[1], Abdelmajid Bybi[2], Hilal Drissi[3], El Ayachi Chater[4]
Mohammed V University in Rabat, Higher School of Technology of Salé, LASTIMI, Salé, Morocco[1, 3, 4]
Mohammed V University in Rabat, Higher School of Technology of Salé, MEAT, Salé, Morocco[2]

***Abstract*—This study explores the implementation of a Dose Archiving and Communication System (DACS) in Moroccan healthcare, highlighting the importance of X-ray dose management in modern radiology. It emphasizes patient safety and the ALARA principle to minimize radiation exposure while maintaining diagnostic accuracy. The research discusses advancements in imaging technologies, such as dose-reduction algorithms and real-time monitoring systems. A survey of 1000 healthcare professionals reveals significant challenges in X-ray dose management, including poor dose tracking, regulatory non-compliance, and inadequate radiation protection training. Noteworthy findings reveal that 10% of patients received doses exceeding 5 Gray, underscoring the exigency for robust dose management systems. The article delineates a strategic implementation approach for DACS in Moroccan hospitals, comprising meticulous needs assessment, infrastructure fortification, and stakeholder engagement. By harnessing cloud-based storage, blockchain technology, and industry-standard encryption protocols, the envisioned DACS endeavors to furnish a secure, scalable, and efficient framework for radiation dose management. This holistic approach, underpinned by empirical statistics regarding training in radiation protection, network infrastructure, and DACS implementation strategies, aims to elevate patient outcomes and ensure stringent regulatory compliance.**

Keywords*—DACS; Real-time monitoring; radiation protection; radiology practice; healthcare professionals; x-ray doses; regulatory compliance; patient safety; Moroccan healthcare

I. Introduction

X-ray dose management represents a fundamental aspect of contemporary radiology practice, emphasizing the ethical imperative to prioritize patient safety while harnessing the diagnostic potential of X-ray imaging. By fostering a culture of radiation stewardship and embracing evidence-based strategies, healthcare institutions can uphold the principles of ALARA (As Low As Reasonably Achievable) and deliver high-quality care that maximizes clinical efficacy while minimizing radiation-related risks [1].

In the realm of modern medical imaging, X-ray technology stands as a cornerstone for diagnostic and therapeutic purposes, facilitating crucial insights into the human body's intricate structures. However, alongside its undeniable benefits, the utilization of X-ray radiation carries inherent risks, particularly concerning cumulative radiation exposure and its potential adverse effects on patients and healthcare professionals alike.

Effective X-ray dose management encompasses various dimensions, including dose monitoring, optimization of imaging protocols, equipment calibration, personnel training, and patient education. Through meticulous monitoring and analysis of radiation doses delivered during diagnostic and interventional procedures, healthcare providers can gain valuable insights into radiation utilization patterns, identify potential areas for improvement, and tailor interventions to mitigate unnecessary exposure.

Within this framework, Garba et al. [2] conducted research focusing on the development of a manual radiation dose management system to monitor and track radiation doses and scan parameters for brain CT scans. The system monitored CTDI vol and DLP, using notification values to identify procedures requiring optimization. Data analysis was conducted to compare with national and international diagnostic reference levels (DRLs) to ensure compliance and enhance patient safety. Heron et al. [3] examined the impact of X-ray-based medical imaging on staff safety and explored how new technologies affect medical staff's exposure to X-rays. They highlighted the crucial importance of using protective measures and ongoing training. Polizzi-et al. [4] carried out a study to standardize X-ray cabinet irradiator dose, geometry, and calibration reporting, focusing on a dual X-ray source cabinet irradiator (CIXD, Xstrahl Limited, UK). They assessed dose distribution under various experimental conditions using methods such as half-value layer (HVL) measurement, profile measurements, and output calibration with an ion chamber, alongside two weeks of constancy measurements. Film measurements evaluated percent depth dose and homogeneity. The X-ray tubes showed an output of 1.27 Gy/min with an HVL of 1.7 mm Cu. Simultaneous operation of the tubes reduced the heel effect observed in individual tubes. Despite a 15% dose inhomogeneity within the tray area, film measurements indicated only minor nonuniformities. Additionally, Silva et al. [5] undertook a study to investigate and evaluate the radiation doses received by professionals during chest CT scans and to assess the effectiveness of personal protective equipment (PPE). Computational scenarios were simulated using pediatric (1 and 10 years old) and adult virtual anthropomorphic phantoms to represent patients and professionals. The MCNP 6.2 Monte Carlo code was employed to determine conversion coefficients for equivalent (CC[HT]) and effective (CC[E]) doses. Another noteworthy contribution to radiation protection research was offered by Kawauchi et al. [6]. Their study emphasized the importance of protecting lenses during cerebral angiography examinations to ensure patient lens safety. To assess lens doses, they employed both a phantom and a real-time dosimeter. Additionally, they computed an artifact index for evaluating image quality through pixel and noise analysis.

Healthcare professionals and patients face increased health risks from radiation overdoses due to inadequate use of protective measures and passive dosimeters during imaging exams. Developing effective X-ray dose management systems is essential to mitigate these risks by ensuring rigorous dose monitoring and adherence to safety protocols. In this context, Choi et al. [7] conducted a study focusing on implementing a Dose Archiving and Communication System (DACS) in a large healthcare system to manage radiation doses. Liu et al. [8] provide a comprehensive review of DACS in radiation oncology, focusing on its capabilities, challenges, and future prospects. Furthermore, Faggioni et al. [9] describe the implementation and evaluation of a DACS tailored for pediatric cardiac catheterization procedures. The study evaluates how DACS improves radiation dose monitoring and management in pediatric settings. Rehani et al. [10] explore the comprehensive landscape of radiation dose management systems, including DACS, discussing challenges in monitoring doses across various medical imaging modalities. Wang et al. [11] examine the advancements in DACS technology and its role in enhancing radiation dose management in clinical settings. Moreover, Martin et al. [12] explore how the implementation of DACS affects clinical workflow and patient care outcomes, highlighting both benefits and challenges.

We have designed an innovative Dose Archiving and Communication System (DACS) that offers several significant advantages. This system operates independently and adapts seamlessly to any IT infrastructure installed in the relevant departments. Unlike other solutions, our DACS is engineered to meet the constraints of network infrastructure and limited access, providing exceptional flexibility and compatibility. It can be used with both new equipment technologies and older technologies, making it a durable and adaptable solution. Furthermore, our system allows for real-time dose monitoring, with alerts and notifications to ensure optimal management of prescribed examination protocols for patients and the doses absorbed by healthcare personnel during their daily tasks. This level of control and responsiveness helps improve the safety and efficiency of radiological practices.

This paper is organized into seven sections. The first section is Introduction. Section II describes the general context. Section III explores the study's foundational aspects and methodology. Section IV is devoted to elucidating the dose system management. Following that, Section V sheds light on the results and fosters discussions. Then, Section VI concentrates on outlining an approach for implementing dose archiving and communication systems in healthcare institutions. Finally, Section VII presents the conclusion.

II. General Context

X-ray dose management emerges as a pivotal discipline within radiology and healthcare at large, aiming to optimize the utilization of X-ray imaging while minimizing radiation exposure risks. By implementing comprehensive strategies, protocols, and technologies, X-ray dose management endeavors to strike a delicate balance between acquiring diagnostically valuable images and safeguarding patient safety. Moreover, advancements in imaging technology, such as dose-reduction algorithms, dose-tracking software, and real-time dose monitoring systems, offer invaluable tools for enhancing X-ray dose management practices. These innovations empower healthcare professionals to optimize imaging parameters, adjust radiation doses based on patient characteristics and clinical indications, and ensure that diagnostic goals are achieved with the lowest feasible radiation exposure.

In the domain of X-ray exposure, a nuanced understanding of various dose metrics is indispensable for assessing radiation risks and ensuring patient safety. These metrics provide crucial insights into the amount of radiation absorbed by individuals during imaging procedures. Among the key types of X-ray doses, the Entrance Skin Dose (ESD) stands out as it quantifies the radiation absorbed by the skin at the point of entry of the X-ray beam, serving as a critical indicator of potential skin effects. Additionally, Organ Dose evaluation allows for a targeted assessment of radiation absorbed by specific organs or tissues, recognizing their differing sensitivities and facilitating a more accurate estimation of associated health risks. The Effective Dose (ED) metric goes further by synthesizing the varying sensitivities of different tissues and organs, offering a comprehensive assessment of the overall risk posed by a particular radiation exposure, measured in Sieverts (Sv). Dose Area Product (DAP) is instrumental in quantifying the total radiation delivered to a specific area during an X-ray procedure, factoring in both radiation intensity and exposed area. Peak Skin Dose (PSD) is particularly pertinent in interventional radiology procedures, identifying the maximum skin dose reached during a specific imaging intervention. Cumulative Dose accounts for the total radiation accumulated over time from multiple X-ray exposures, particularly crucial for individuals undergoing frequent medical imaging. Finally, Effective Dose Equivalent (EDE) provides a refined measure of radiation risk by considering the biological harm associated with different types of ionizing radiation, thereby guiding radiation protection strategies. For medical professionals, radiologists, and radiation safety experts, a comprehensive grasp of these dose metrics is essential in ensuring that X-ray procedures are conducted with utmost precision and minimal risk to patients, while still yielding valuable diagnostic insights [13-15].

The legal framework governing nuclear and radiological safety, security, and ionizing radiation control in Morocco is outlined in references [16-19]. These documents articulate three fundamental principles of radiation protection: justification, optimization, and limitation. Justification dictates that no activity involving exposure to ionizing radiation should occur unless it produces a positive economic, social, or other benefit that outweighs potential health risks. Optimization requires minimizing individuals' exposure to ionizing radiation to the fullest extent possible, taking into account economic and social considerations. Limitation mandates that cumulative doses from all activities must not exceed the dose limits specified by regulations.

To complement these regulatory efforts, several agencies have been established to serve specific purposes such as dosimetry monitoring, calibration, and metrology of ionizing radiation devices, as well as control and expertise in radiation protection, quality assurance in medical imaging, radiological environmental monitoring, and radiation protection training. These agencies include "The National Center for Radiation Protection of the Ministry of Public Health," "The National Commission for Radiation Protection," "The National Commission for Nuclear Safety," "The Department of Nuclear Energy of the Ministry of Energy and Mines," and "The National Center for Energy of Nuclear Sciences and Techniques" [16-19].

The integration of dosimetry control and monitoring is an increasingly prevalent trend within Moroccan healthcare establishments, influenced by various challenges: technological (quality, safety, and innovation), regulatory, and economic considerations. This research is crafted for the benefit of all practitioners involved in ionizing radiation. The primary objectives of this study revolve around the adoption of best practices in radiation protection. Additionally, it aims to promote the utilization of both individual and collective protective measures. Lastly, the research emphasizes the significance of monitoring the dosimetry of each individual to ensure personal protection and minimize absorbed radiation doses.

III. Study Background and Methodology

While technology continues to evolve and regulatory standards change, the field of X-ray dose management remains a major challenge for the Moroccan authorities, particularly in terms of the doses absorbed by healthcare professionals.

To understand users' needs in X-ray dose management, a survey was conducted among 1000 healthcare professionals. The results revealed that the main challenges encountered included: X-ray dose tracking, regulatory and normative compliance and lack of adequate training, underscoring the importance of an integrated dose management system to address users' diverse needs and enhance patient and worker safety.

The significance of network infrastructure in the context of radiology departments is paramount for enhancing radiation protection and dose management. A robust network infrastructure plays a crucial role in facilitating the integration of advanced technologies and tools that contribute to the overall safety and efficiency of x-rays practices [20-22]. Several key points highlighting the importance of network infrastructure in this regard:

1) *Data management and storage:* Network infrastructure enables seamless data management and storage of radiological images and patient information. This centralized approach allows for efficient access, retrieval, and secure archival of critical data, supporting comprehensive dose monitoring and analysis.

2) *Integration of imaging systems:* A well-developed network allows for the integration of various imaging systems and devices within the radiology department. This integration enhances the coordination and interoperability of equipment, ensuring a streamlined approach to dose control and radiation protection protocols.

3) *Real-time monitoring and analysis:* Network connectivity facilitates real-time monitoring of imaging procedures and radiation dose levels. With instant access to this information, healthcare professionals can make informed decisions promptly, adjusting protocols as needed to optimize radiation exposure for patients and staff.

4) *Telemedicine and remote consultations:* Network infrastructure supports telemedicine initiatives and remote consultations, enabling radiologists to collaborate and share expertise regardless of physical location. This capability contributes to more extensive knowledge exchange, fostering best practices in radiation protection.

5) *Implementation of dose tracking systems:* Dose tracking systems, crucial for monitoring and managing radiation exposure, rely on a robust network infrastructure. The connectivity provided by the network allows for the seamless collection, analysis, and reporting of dose data, aiding in the implementation of dose optimization strategies.

6) *Security and compliance:* A secure network infrastructure is essential to protect sensitive patient data and ensure compliance with regulatory standards. Compliance with security protocols is integral to maintaining the integrity of radiation protection measures and preventing unauthorized access to patient information.

7) *Education and training programs:* Network connectivity supports online education and training programs for healthcare professionals involved in radiology. This allows for continuous learning, ensuring that the staff stays updated on the latest advancements in radiation protection practices.

Dose Archiving and Communication System (DACS) aims to enhance dose monitoring and management practices in medical imaging by providing comprehensive solutions for capturing, storing, and analyzing dose data. Through advanced tracking and reporting functionalities, DACS facilitates the optimization of radiation dose levels, ensuring patient safety, regulatory compliance, and the quality of diagnostic imaging procedures. By centralizing dose data and promoting data-driven decision-making, DACS empowers healthcare providers to improve patient care and enhance operational efficiency in medical imaging facilities.

In the context of analyzing the needs for managing and analyzing X-ray doses, understanding users (Biomedical, Radiology, Oncology and Surgery staff) specific requirements and the current challenges faced by professionals in this field is paramount. Our system is a comprehensive solution designed to manage and monitor radiation doses administered to patients during radiological procedures. Upon launching the system, users are greeted with a secure authentication screen, ensuring that only authorized personnel can access sensitive patient and dose information. Once logged in, users are directed to the main dashboard, which serves as the central hub of the system. The interface is intuitively organized into several key sections, providing seamless navigation and functionality.

The settings section allows administrators to configure system parameters, user roles, and access permissions, ensuring that the system operates according to institutional protocols and user needs. The statistics display provides real-time analytics and visualizations of dose data, including charts and graphs that illustrate trends, compliance with safety standards, and individual patient dose histories. This feature empowers healthcare professionals to make informed decisions and optimize patient safety. Additionally, the dashboard includes a comprehensive dose archive section, where detailed records of all administered doses are stored and easily retrievable. The interface also supports advanced search capabilities, enabling users to quickly locate specific patient records or procedure details. Overall, the system interface is designed to be used friendly, efficient, and secure, facilitating x-ray dose management and communication within radiology departments.

Our solution is designed with four primary objectives (Fig. 1) to ensure optimal radiation dose management and patient safety. First, the collect objective focuses on the systematic collection and secure storage of dosimetric data. This involves gathering detailed records of all administered doses, ensuring that data integrity and confidentiality are maintained. Second, the monitor objective enables continuous, real-time tracking of patient radiation doses. This feature provides healthcare professionals with immediate feedback on radiation exposure levels, allowing for timely adjustments and interventions. Third, the evaluate objective involves comprehensive statistical analysis of dosimetric information. By utilizing advanced analytics tools, the system can identify trends, generate reports, and support evidence-based decision-making to improve radiation safety protocols. Finally, the optimize objective aims at the assessment and enhancement of radiation dose safety and efficacy. This includes evaluating current practices, implementing optimization strategies, and ensuring compliance with regulatory standards to minimize patient exposure while maintaining diagnostic image quality. Together, these objectives create a robust framework for x-ray dose management in radiological practices.

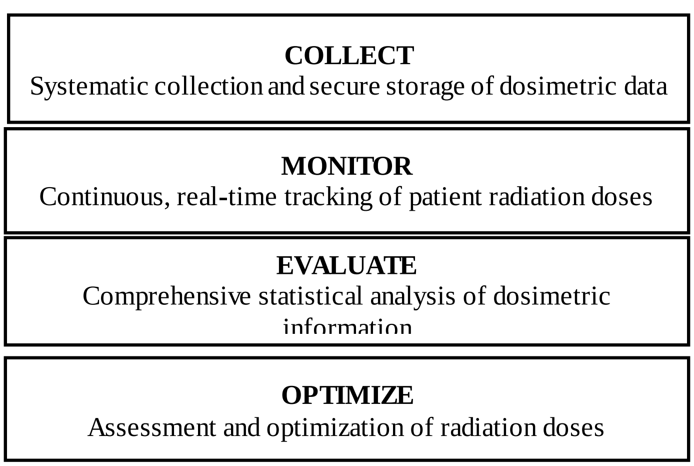

Fig. 1. Dose archinving and communication system objectives.

In conclusion, a robust network infrastructure is indispensable for creating a connected and technologically advanced radiology department. By enabling seamless data management, integrating imaging systems, facilitating real-time monitoring, supporting telemedicine, implementing dose tracking systems, ensuring security and compliance, and fostering education programs, the network plays a pivotal role in enhancing radiation protection and dose control in medical imaging based on X-rays.

IV. X-Ray Dose Management

According to our survey, users' specific needs vary depending on their roles and usage contexts. Radiologists and medical imaging technicians require effective tools to monitor and evaluate x-ray doses administered to patients while optimizing diagnostic image quality and controlling the doses absorbed by them. Similarly, radiation protection and safety professionals need dose management systems to ensure compliance with regulatory standards and worker safety. Current challenges encountered by professionals in this domain include the increasing complexity of imaging equipment, which makes dose management more challenging, as well as time and resource constraints that limit the ability to implement effective dose management practices. Additionally, compliance with regulatory standards and safeguarding patients' health data are critical considerations.

By conducting a comprehensive analysis of users' needs and the challenges faced by professionals in managing and analyzing X-ray doses, we have developed effective solutions tailored to their requirements. Fig. 2 illustrates an overall structure of our system application area.

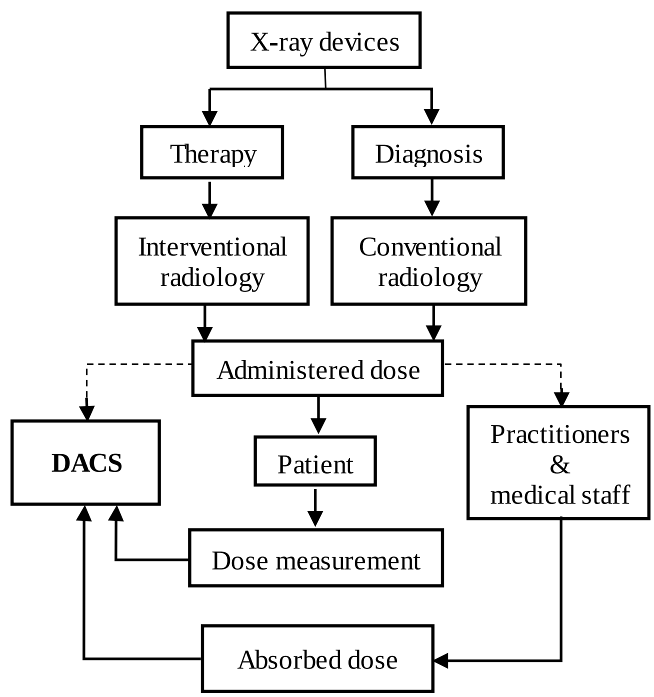

Fig. 2. General diagram and application area.

In the field of X-ray based medical imaging, two primary types of equipment are utilized: those employed in conventional radiology for diagnostic purposes and those utilized in interventional radiology for therapeutic interventions. Prior to conducting an examination, technicians program the dose of X-rays to be administered to the patient based on various parameters such as the type of exam and patient anatomical characteristics. Following exposure, the patient absorbs a dose of X-rays, which is measured during image detection using radiographic or fluoroscopic imaging. Simultaneously, medical personnel present during the examination are also exposed to X-ray doses, which vary depending on their proximity to the radiation source and the protective measures employed, suchas lead aprons. All these doses, both those administered to patients and those absorbed by medical personnel, are then transmitted to the Dose Archiving and Communication System for storage and analysis. Additionally, this system conducts equipment checks based on these doses and the utilized examination protocols, ensuring adherence to safety standards and the quality of radiological exams performed.

To understand the framework and components of our Dose and Archiving Communication System, we present a modeling overview (Fig. 3) including:

- Data Acquisition and Integration: This component is responsible for collecting dose data from x-ray devices, integrating it into a standardized format, and transmitting it to the central storage.
- Central Dose Data Storage and Management: This component stores and manages the dose data in a centralized database, facilitating efficient archiving, retrieval, and analysis.
- User Interface: The user interface provides a dashboard for visualizing dose data, and reporting functionalities.
- Security and Compliance: This component ensures data security through encryption, access control mechanisms, and maintains compliance with regulatory requirements.

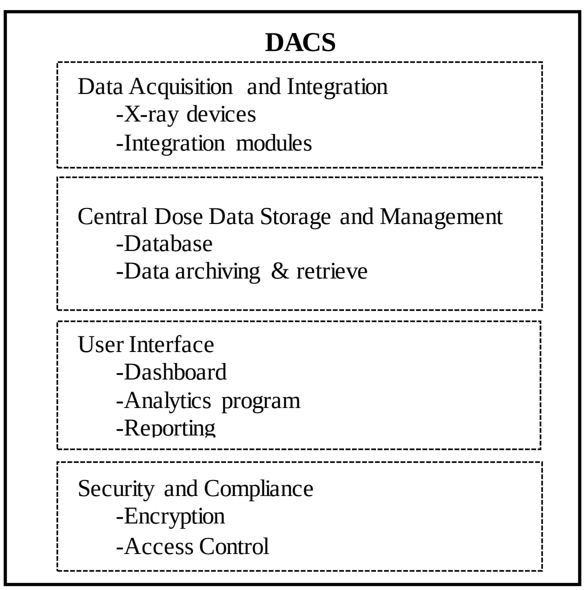

Fig. 3. Overview of DACS architecture.

Designing an effective architecture for a Dose Archiving and Communication System requires careful consideration to ensure both flexibility and security. An optimal approach involves the integration of modular components that can adapt to evolving requirements while maintaining robust security measures. Technologies such as cloud-based storage solutions offer scalability and accessibility, allowing for seamless data archiving and retrieval [23]. Additionally, blockchain technology [24-25] provides a secure and transparent framework for data communication and authentication, ensuring the integrity and traceability of dose data. Implementation of industry standard encryption protocols further fortifies data security, safeguarding sensitive information against unauthorized access. By leveraging these technologies synergistically, a DACS architecture can achieve the delicate balance between flexibility and security, laying the foundation for efficient dose management and analysis.

In the diverse landscape of medical imaging, a range of Dose Archiving and Communication Systems are available, each designed to address specific needs and requirements within healthcare facilities. Integrated Picture Archiving and Communication Systems (PACS) with dose monitoring capabilities offer a consolidated approach, allowing for the storage and management of both medical images and dose data within a single platform. While these systems provide basic dose tracking functionalities, they may lack the advanced analytics and reporting features found in standalone solutions. Standalone DACS, on the other hand, are dedicated platforms focused solely on dose monitoring and management. These systems offer comprehensive dose tracking, analysis, and reporting capabilities, enabling healthcare providers to perform in-depth assessments and trend analyses. Cloud based DACS leverage the scalability and accessibility of cloud computing technology, providing healthcare facilities with flexible and remotely accessible dose management solutions. By centralizing dose data in the cloud, these systems enable seamless collaboration and data sharing across multiple locations. Additionally, some medical imaging equipment vendors offer proprietary solutions tailored to their specific imaging systems. These vendor specific DACS are seamlessly integrated into the equipment's software and workflow, providing healthcare providers with specialized features optimized for their imaging modalities. However, they may lack the flexibility and interoperability of standalone or cloud based DACS. Healthcare providers must carefully evaluate the features, scalability, interoperability, and cost effectiveness of each solution to determine the most suitable option for their organization, considering factors such as existing infrastructure, budget constraints, and regulatory compliance requirements.

Our dose management system is a specialized platform designed to effectively manage, archive, and communicate dose data from medical imaging procedures and it provide several features as below (Fig. 4):

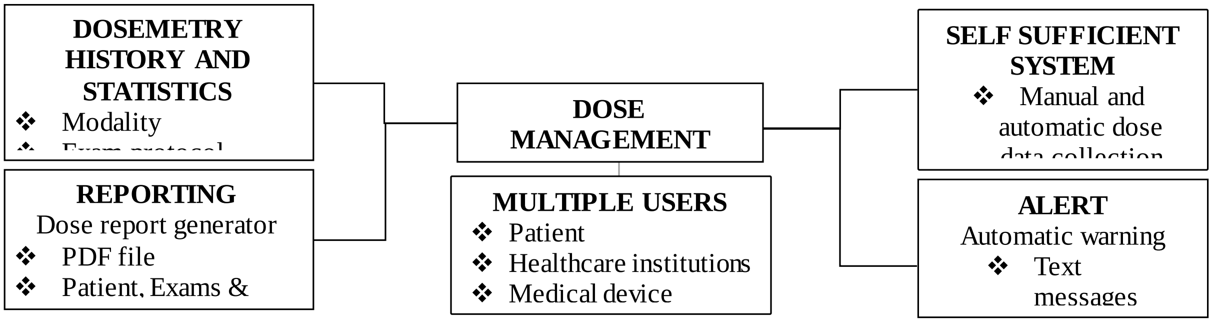

Fig. 4. Features of the DACS system.

A. Dosimetry History and Statistics

DACS facilitates the integration and comprehensive analysis of dose data across various imaging modalities. This section outlines its capabilities in documenting exam protocols and providing customizable statistical analysis over different time periods.

1) Modality: DACS seamlessly integrates with various imaging modalities, capturing dose data from x-ray, CT scans, and more.

2) Exam protocol: Detailed documentation of exam protocols used during imaging procedures, ensuring comprehensive data capture.

3) Period: Provides a comprehensive dose history and statistical analysis over customizable time periods, facilitating trend identification and dose optimization efforts.

B. Self Sufficient System

This section highlights the DACS features that ensure system autonomy and flexibility in dose data management.

1) Manual and automatic dose data collection: DACS supports both manual entry and automated collection of dose data, ensuring accuracy and flexibility.

2) Remote access: Enables secure remote access to dose data and system functionalities, allowing users to monitor and manage dose information from anywhere, at any time.

C. Multiple Users

This part describes how DACS accommodates various users, from patients to healthcare institutions and medical device suppliers, enhancing transparency, collaboration, and centralized dose management.

1) Patient access: Empowers patients to access their own dose history and reports, promoting transparency and patient engagement in their healthcare journey.

2) Healthcare institutions: Facilitates centralized dose management across healthcare facilities, allowing institutions to monitor dose levels, compliance, and performance across departments and modalities.

3) Medical device suppliers: Provides access to dose data for medical device suppliers, fostering collaboration and optimization of imaging equipment performance.

D. Reporting

This segment outlines DACS's capabilities in generating detailed and customizable dose reports for both healthcare providers and patients.

1) Dose report generator: Generates detailed and customizable reports in PDF format, incorporating patient information, exam details, and dose data for comprehensive documentation.

2) Patient centric reports: Delivers personalized dose reports to patients, enhancing communication and understanding of dose exposure and associated risks.

E. Alert System

This category details DACS's alert features, ensuring timely intervention and communication through automatic alerts and notifications.

1) Automatic alerts: DACS triggers automatic alerts for dose threshold breaches or abnormal dose patterns, ensuring timely intervention and dose optimization.

2) Text messages and email notifications: Alerts are disseminated via text messages or email to designated recipients, facilitating prompt action and communication among relevant stakeholders.

The Dose Archiving and Communication System streamlines dose management processes, enhances patient safety, and promotes collaboration among healthcare providers and stakeholders. With its advanced features and user-friendly interface, our solution empowers healthcare organizations to effectively manage dose data, optimize imaging practices, and deliver high-quality patient care.

V. Results and Discussions

The dashboard of our Dose Archiving and Communication System is meticulously designed to offer the users a comprehensive snapshot of key statistics and metrics crucial for understanding the system's performance and ensuring patient safety. Upon accessing the system through secure login protocols, users are greeted with the main dashboard, where they can quickly grasp essential information. This includes the total number of patients, providing an overview of the volume of dosimetric data within the system, and the average dose per patient, offering insight into the typical radiation exposure experienced by individuals undergoing procedures. Additionally, a dose distribution chart visually represents the spread of doses across different ranges, aiding in identifying any anomalies or trends.

The procedure statistics section presents users with valuable insights into the total number of procedures performed, segmented by procedure type, along with the average doses administered for each procedure category. A timeline graph depicting procedure volumes over time facilitates the tracking of procedural trends, enabling proactive decision-making and resource allocation. Real-time monitoring capabilities allow users to stay updated on current active procedures and receive prompt alert notifications for doses that exceed predefined safety thresholds, ensuring timely intervention and adherence to safety protocols.

The dashboard's analytical section offers in-depth analysis and historical perspectives, with features such as dose trends over time and patient specific dose histories presented in a user-friendly format. Compliance reports provide transparency regarding adherence to safety standards, while benchmarking facilitates performance comparison against industry norms, fostering a culture of continuous improvement and excellence. Finally, the optimization insights section leverages data driven recommendations derived from statistical analysis to enhance dose safety and efficacy, empowering users to make informed decisions aimed at improving patient outcomes and optimizing resource utilization. Through its intuitive interface and comprehensive feature set, our DACS dashboard facilitates seamless access to critical dosimetric data, empowering stakeholders with the insights needed to drive informed decision-making and deliver high-quality patient care.

The patient dose summary collected from different healthcare institutions provides a comprehensive overview of radiation exposure among of 350 patients over a year (Fig. 5). On average, each patient received a dose of 4.5 Gray (Gy), a unit measuring the absorbed radiation energy. The distribution of doses reveals that 40% of the patients fell into the low dose category, receiving between 0 and 2 Gy. The majority (about 50%) received a medium dose ranging from 2 to 5 Gy, while 10% were exposed to high doses exceeding 5 Gy. This summary highlights the variation in radiation exposure levels among the patients during this period and underscores the need for careful monitoring and management of radiation doses in clinical settings.

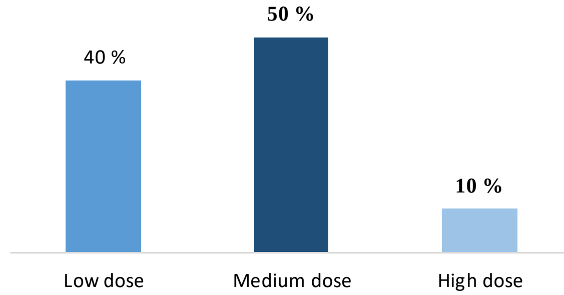

Fig. 5. Patient dose summary and distribution.

The Table I provides a detailed breakdown of the dose absorbed by ten patients across various medical procedures. Each row corresponds to a patient, while the columns represent different procedures undertaken by them. The values within the table denote the dose of radiation absorbed by each patient during the respective procedures. This comprehensive overview allows for a comparative analysis of radiation exposure among patients undergoing different medical interventions. By examining the data within the table, trends in radiation dosage across procedures and variations among patients become apparent. Such insights are crucial for ensuring the optimization of radiation doses, minimizing unnecessary exposure, and enhancing patient safety in clinical settings. Furthermore, this information facilitates informed decision-making by healthcare professionals regarding the appropriate dosage levels for specific procedures based on individual patient characteristics and medical requirements.

To calculate the risk associated with X-ray doses, the first step is to determine the effective dose, which is measured in Sieverts (Sv). The effective dose accounts for the type of radiation and the varying sensitivity of different tissues and organs. This measure provides an overall risk estimate from radiation exposure [26]. The effective dose is calculated using the formula:

$$E=\sum(Dt \cdot Wr \cdot Wt) \quad (1)$$

TABLE I. DOSE ABSORBED FOR DIFFERENT PROCEDURES ACROSS 10 PATIENTS

Procedure / Patient	Chest CT	Abdomen CT	Brain CT	Cardiac CT	Lumbar Standard	Extremity Standard	Chest Standard	Mammography	Dental
Patient 1	6.1	*	*	*	1.4	*	0.2	0.21	*
Patient 2	*	5.3	1.6	*	*	*	*	*	0.25
Patient 3	6	5.2	*	*	*	0.2	0.1	0.20	
Patient 4	*	*	1.5	1.6	*	*	0.2	*	0.23
Patient 5	6.2	*	*	1.5	*	0.1	*	*	0.3
Patient 6	*	5.4	1.4	*	1.3	*	*	0.22	*
Patient 7	*	*	*	*	1.2	*	0.2	*	0.31
Patient 8	*	5	*	1.4	*	0.3	0.1	*	*
Patient 9	6	4.8	*	*	*	*	*	*	0.2
Patient 10	7	*	1.8	*	1	*	0.12	0.3	*

Where:

E is the effective dose. Dt is the absorbed dose in tissue t, Wr is the radiation weighting factor (depends on the type of radiation, usually 1 for X-rays) and Wt is the tissue weighting factor (varies for different tissues).

Tissue weighting factors (Wt) are used to account for the varying sensitivity of different tissues to radiation. These factors, provided by the International Commission on Radiological Protection (ICRP) [27], help in calculating the contribution of each tissue or organ to the effective dose. By applying these factors (Table II), the effective dose calculation becomes more accurate, reflecting the differential risk of radiation exposure to various tissues.

TABLE II. TISSUE WEIGHTING FACTORS

Tissue or Organ	ICRP 60	ICRP 103
Gonads	0.20	0.08
Red bone marrow	0.12	0.12
Lung	0.12	0.12
Colon	0.12	0.12
Stomach	0.12	0.12
Breast	0.05	0.12
Bladder	0.05	0.04
Liver	0.05	0.04
Esophagus	0.05	0.04
Thyroid	0.05	0.04
Skin	0.01	0.01
Bone surface	0.01	0.01
Brain		0.01
Salivary glands		0.01

A comprehensive empirical investigation was conducted within healthcare institutions in Morocco to assess the implementation of radiation protection measures in both diagnostic and therapeutic procedures. The study's objectives encompassed evaluating adherence to the three fundamental principles of radiation protection and examining infrastructure, notably computer network connectivity, across services employing ionizing radiation sources. To accomplish this, a questionnaire was administered to over 1000 healthcare professionals, comprising radiology technicians, radiologists, surgeons, biomedical technicians, and biomedical engineers, representing diverse healthcare facilities across different regions of the kingdom. Key areas of inquiry included training in radiation protection, utilization of personal protective equipment, availability of individual dosimeters, effectiveness of control and monitoring systems, and comprehensiveness of dosimetry reports. Survey results encompass a broad spectrum of hospital structures spanning various regions in Morocco, with contributions from multiple healthcare institutions as delineated in Table III.

Professionals from various hospital services participated in the survey, with representation as follows: the biomedical department accounted for 13% (Fig. 6), where technicians and engineers, serving as both internal and external interfaces, manage device-user interaction and liaise with suppliers. The radiology department accounted for 63% (Fig. 6), including radiology technicians and managers in the medical imaging department. The oncology department represented 7% (Fig. 6), comprised of radiation therapists and radiologists, while the surgery department contributed 17% (Fig. 6), involving traumatologists, neurologists, and other medical personnel.

TABLE III. HEALTHCARE INSTITUTIONS PARTICIPATING IN THE STUDY

Healthcare institutions	Number
University Hospital Center	5
Regional Hospital Center	14
Provincial Hospital Center	60
Military Hospital	4
Clinic	10
Radiology Center	15

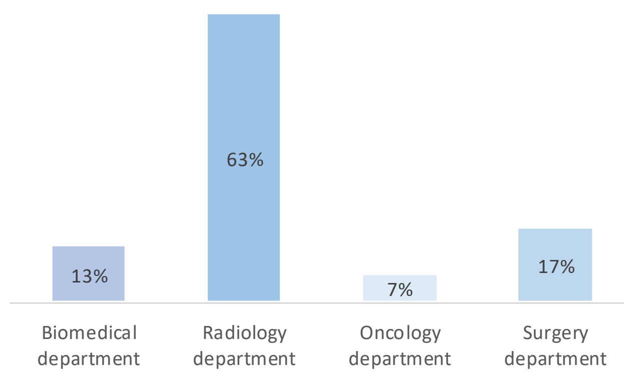

Fig. 6. Participating departments.

In the array of healthcare institutions, a significant portion of healthcare professionals, totaling 58%, lack training in radiation protection and are unaware of the relevant standards (Fig. 7). This gap primarily stems from inadequacies in the academic curriculum of universities and higher education institutions, which fail to sufficiently cover radiation protection. Additionally, there is a dearth of coverage on this topic in the continuing education courses pursued by these professionals, exacerbating the issue. The study reveals that only 42% have received training on radiation protection and its critical implications for both patient well-being and healthcare practitioners (Fig. 7).

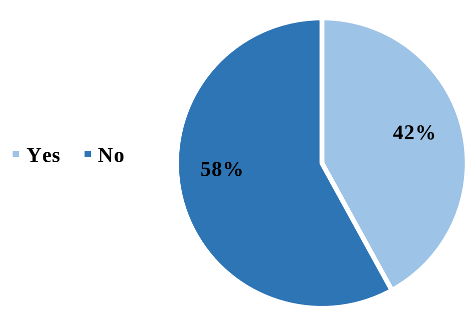

Fig. 7. Radiation safety-trained professionals.

Adhering to dose limits ensures that the radiation risk from all controllable sources of ionizing radiation remains sufficiently low to pose no concern to individuals. The emphasis lies not in solely controlling the radiological risk from one specific source, but in restricting individual risk arising from exposure to all sources. This underscores the necessity of utilizing both individual protective gear such as lead skirts, lead gowns, thyroid covers, X-ray gloves, and X-ray glasses, as well as collective protective measures like lead walls and X-ray screens [28-35]. According to the findings, 26% of practitioners utilize lead gowns (Fig. 8), 10% use both thyroid covers and lead gowns (Fig. 3), while a notable 64% do not employ any protective measures (Fig. 8).

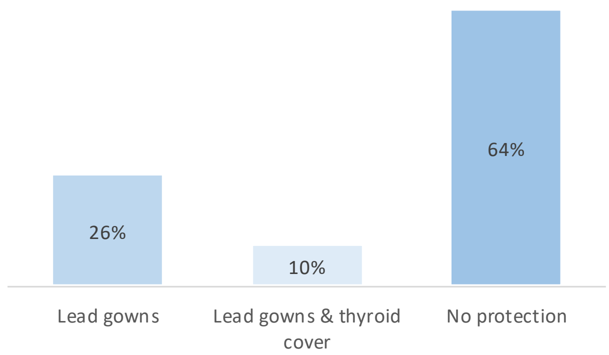

Fig. 8. Individual protection items.

Regulations stipulate the monitoring of external exposure to ionizing radiation in areas where individuals may encounter such risks, necessitating the use of individual dosimeters. This practice evaluates the radiation dose received by each person during their professional activities, ensuring ongoing safety measures and facilitating the early detection of any anomalies for timely intervention. It's essential to clarify that while this monitoring doesn't provide direct protection, its purpose is to maintain safety conditions. The associated risk with a specific radiation dose is determined by the likelihood of an individual experiencing particular radiation-induced effects upon exposure.

Within the purview of the National Center for Radiation Protection (NCRP), the dosimetry-monitoring department assumes responsibility for the provision and management of individual dosimeters used in medical settings, both private and public. Under the authority of the Ministry of Health, the NCRP oversees the monitoring of external exposure for individuals engaged in tasks involving ionizing radiation. Typically, this monitoring is reserved for medical and paramedical personnel operating within controlled areas, particularly those classified as category A, who are anticipated to be occupationally exposed to an effective dose exceeding 6 millisieverts over a 12-month period and directly involved in radiation-related tasks.

The primary objectives of individual dosimetry monitoring encompass several key aspects:

1) Quantification of ionizing radiation levels: The foremost purpose is to measure and quantify the doses of ionizing radiation accumulated by an individual during their occupational activities. This data provides crucial information regarding the extent of radiation exposure experienced by workers.

2) Empowerment of occupational physicians: Individual dosimetry monitoring empowers occupational physicians to take necessary actions based on the radiation exposure levels detected. This may include implementing supplementary medical examinations or temporarily relocating individuals from high-risk areas to mitigate potential health risks associated with radiation exposure.

3) Effective monitoring and regulation of working conditions: By utilizing individual dosimetry data, employers can effectively monitor and regulate working conditions to ensure compliance with radiation safety standards and guidelines. This proactive approach aids in maintaining a safe and healthy work environment for employees exposed to ionizing radiation.

For all personnel exposed to ionizing radiation falling within categories A and B, the utilization of a passive dosimeter is obligatory. This dosimeter must be worn either at chest level or, if not feasible, on the belt beneath protective clothing (such as a lead gown) for the entire duration of work. At the end of the workday, the dosimeter is securely stored in a designated area, ensuring distance from any sources of radiation, heat, or humidity. Subsequently, it is dispatched to the relevant agency responsible for passive dosimetry either monthly or, exclusively for category B workers, on a quarterly basis. The measured results are quantified in millisieverts (mSv), and the outcome report is conveyed in an individualized and nominative manner to the occupational physician, who then communicates them to the healthcare professionals. The survey's results pertaining to this protocol are depicted in Fig. 9. The statistics indicating that 54% of healthcare professionals use passive dosimeters while 46% do not underscore the varying levels of adherence to radiation safety practices within healthcare settings. Those utilizing passive dosimeters benefit from continuous monitoring of radiation exposure, enabling them to proactively manage risks and adhere to regulatory requirements such as the ALARA principle. In contrast, those not using dosimeters may potentially overlook the cumulative effects of radiation exposure, highlighting a need for enhanced awareness and adherence to safety protocols across the healthcare field.

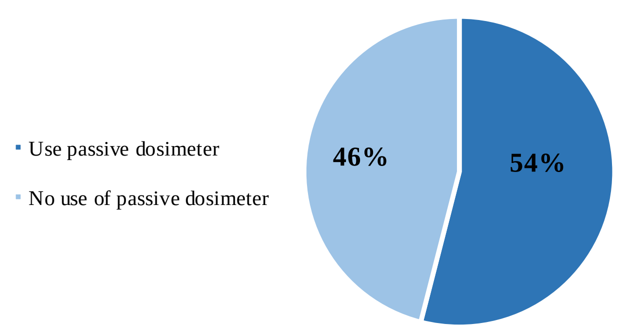

Fig. 9. Monitoring radiation exposure.

When X-rays interact with matter, they induce various effects primarily because of their capacity to ionize atoms and molecules [36-38]. These effects include ionization, where X-rays possess adequate energy to expel electrons from atoms, resulting in the formation of positively charged ions. This ionization process can disrupt chemical bonds, thereby impacting the structure and functionality of molecules. Furthermore, the ionizing nature of X-rays is central to their utility in medical imaging, but it can also inflict cellular damage by disrupting DNA strands within cells. This mechanism underlies their application in radiation therapy, where X-rays are employed to target and eradicate cancer cells. Additionally, high doses of X-rays can lead to radiation burns on the skin and underlying tissues, necessitating careful control of radiation doses in medical environments. Moreover, prolonged or repeated exposure to X-rays, particularly at elevated doses, heightens the risk of cancer, emphasizing the critical importance of radiation protection measures in both medical and industrial settings. Furthermore, X-rays can induce fluorescence in certain materials, causing them to emit light of characteristic wavelengths, a property exploited in X-ray fluorescence spectroscopy for elemental analysis. Finally, X-rays are extensively utilized in medical diagnostics, including diagnostic radiography, computed tomography (CT) scans, and fluoroscopy, facilitating the visualization of internal bodily structures for the detection and diagnosis of various medical conditions. It is crucial to acknowledge that while X-rays offer significant benefits in medical diagnostics and treatment, adherence to proper precautions and safety protocols is imperative to mitigate potential risks associated with their ionizing nature.

The importance of network infrastructure within radiology departments cannot be overstated, as it is fundamental for improving radiation protection and dose control measures. A resilient network infrastructure is instrumental in enabling the seamless integration of cutting-edge technologies and tools, thereby enhancing the overall safety and efficiency of radiological practices. However, the study findings (Fig. 10) reveal a concerning statistic: only 11% of diverse radiology department spaces have opted to incorporate a computer network, leaving a substantial 89% without such integration. This deficiency has emerged as a significant barrier to the adoption of new technologies that rely on a computer network for essential dose monitoring functionalities.

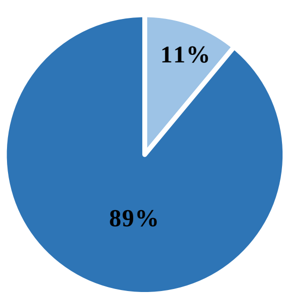

Fig. 10. Network infrastructure implementation.

The effective management of radiation exposure is paramount for both X-ray practitioners and patients alike. Implementing key practices such as utilizing personal dosimetry, maintaining safe distances from X-ray sources, proper collimation, emphasizing accurate positioning and technique, using shielding equipment, and adjusting imaging protocols based on patient parameters are essential steps in minimizing radiation doses while ensuring diagnostic quality. By adhering to these recommendations, X-ray practitioners can safeguard themselves from excessive radiation exposure and contribute to the overarching goal of optimizing patient care. Moreover, ongoing training, open communication, and stringent quality assurance protocols are vital components for maintaining a safe and effective radiological practice. By prioritizing radiation protection measures, X-ray practitioners play a crucial role in promoting both occupational safety and patient well-being within radiology departments.

VI. DACS Implementation Approach

Implementing a Dose Archiving and Communication System in Moroccan hospitals involves several key steps to ensure accurate radiation dose tracking, storage, and communication. This system will enhance patient safety, optimize radiology practices, and comply with regulatory standards. To initiate the implementation, it is crucial to conduct a thorough needs assessment and planning phase. Engage key stakeholders, including radiologists, medical physicists, IT specialists, hospital administrators, and regulatory authorities, to gather comprehensive requirements and understand existing workflows and challenges. Organize meetings and workshops to ensure all perspectives are considered. Evaluate the current radiology and IT infrastructure to identify gaps in radiation dose tracking, archiving, and communication processes. Once the needs assessment is complete, define the technical and functional requirements for the DACS. These requirements should include integration capabilities with existing Radiology Information Systems (RIS) and Picture Archiving and Communication Systems (PACS).

Developing the necessary infrastructure is a key step in implementing DACS. Upgrade or procure the required hardware, such as servers, storage systems, and network infrastructure, to support the new system. Ensure high-speed and secure network connectivity within and between hospitals to facilitate seamless data transfer. Install the DACS software on designated servers and configure it for integration with existing RIS and PACS systems. Proper infrastructure development ensures the system's reliability and performance, supporting efficient radiation dose management. With the infrastructure in place, focus on migrating existing dose records from legacy systems to the new DACS. This process involves validating the accuracy and completeness of the migrated data to ensure no critical information is lost. Integrate the DACS with RIS and PACS for automatic dose data capture and sharing, ensuring interoperability with other hospital systems. Successful data migration and integration are essential for maintaining continuity and accuracy in radiation dose tracking and management.

Implementing a new system requires comprehensive training and effective change management strategies. Develop training programs for radiologists, technologists, IT staff, and administrative personnel, including hands-on training sessions and the provision of user manuals and support materials. Address potential resistance and concerns through regular communication, highlighting the benefits of the new system. By facilitating a smooth transition and ensuring all users are proficient with the new system, hospitals can maximize the benefits of the DACS. Before full-scale deployment, conduct a pilot implementation in a few selected hospitals to test the DACS in a real-world setting. Monitor system performance, user feedback, and data accuracy during this pilot phase. Validate the system's functionality, reliability, and compliance with regulatory standards, making necessary adjustments based on the pilot testing results. This step helps identify and resolve any issues, ensuring a smoother rollout across all hospitals.

Following a successful pilot, proceed with the full-scale deployment of the DACS to all targeted hospitals across Morocco. Provide continuous support and troubleshooting during the initial deployment phase to address any challenges promptly. Establish a monitoring system to track the performance and usage of the DACS, ensuring it meets operational needs and regulatory requirements. Regular monitoring and maintenance are vital to ensure the system operates optimally and continues to benefit the hospital's radiology practices. Post-deployment, regularly evaluate the system's impact on radiation dose management, patient safety, and operational efficiency. Collect and analyze feedback from users to identify areas for improvement. Implement an ongoing process for system enhancements based on evolving needs and technological advancements. Stay updated with international best practices and regulatory changes to ensure the system remains compliant and effective. Continuous evaluation and improvement will help maintain the DACS's relevance and utility in enhancing patient care and radiology workflows.

VII. Conclusion

In Morocco, legislation mandates regular dosimetry monitoring for medical personnel exposed to ionizing radiation, yet the current implementation of such measures remains inadequate, with a significant portion of healthcare professionals lacking training in radiation protection. To address this gap, comprehensive training and education programs must be prioritized, encompassing all personnel working with ionizing radiation. Concurrently, consistent utilization and maintenance of Personal Protective Equipment (PPE) are essential, alongside optimization of imaging procedures to minimize radiation doses while maintaining diagnostic quality. Furthermore, fostering a radiation safety culture within healthcare institutions is crucial, promoting open communication and awareness about safety concerns among healthcare professionals and patients alike.

Implementing a robust dose archiving and communication system offers numerous benefits in enhancing radiation protection efforts. Such a system enables systematic storage and retrieval of radiation dose data, facilitating comprehensive dose monitoring and timely identification of potential overexposure incidents. Additionally, it supports informed decision-making regarding patient care and radiation protection measures. Despite potential obstacles such as technological limitations and concerns about data security and privacy, the benefits of a dose archiving and communication system justify continued efforts to promote its widespread adoption, ultimately ensuring the safety and well-being of both patients and healthcare professionals within radiology departments. However, several obstacles may hinder the successful implementation of a dose archiving and communication system. These may include technological limitations, such as compatibility issues with existing healthcare infrastructure and electronic health record systems. Additionally, concerns regarding data security and patient privacy may pose challenges in establishing trust and compliance with regulatory requirements. Furthermore, resource constraints, including financial limitations and staffing shortages, may impact the feasibility of implementing and maintaining such a system on a large scale. Despite these challenges, the benefits of a dose archiving and communication system in enhancing radiation protection efforts and ensuring the safety of both patients and healthcare professionals justify continued efforts to overcome obstacles and promote its widespread adoption in healthcare settings.

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