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OPTIMISING DATA FLOWS IN HOSPITALS: IMPLEMENTING AN IT SOLUTION FOR STANDARDISING NEUROSURGICAL IMAGING

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ABSTRACT: Objectives: In the context of the decentralisation of medical services and the need for remote multidisciplinary consultations, rapid and secure access to imaging is critical in neurosurgery. This paper aims to develop and implement an integrated IT solution for the standardised exchange of imaging data, creating a digital ecosystem that manages its quality in real time and overcoming the latency and vulnerabilities of conventional transfer methods. Methods: The architecture of the proposed system prioritises data integrity through advanced encryption algorithms and lossless compression. Automatic validation and correction of DICOM metadata was ensured, guaranteeing interoperability between heterogeneous PACS systems. This research was contextualised and validated in the clinical environment of Bacău County Emergency Hospital, analysing the difficulties in transferring imaging data. Results: Preliminary results indicate a significant optimisation of the operational workflow at Bacău County Emergency Hospital, eliminating dependency on physical media and drastically reducing the time required to obtain a second medical opinion. The tool ensures instant access to high-fidelity imaging, facilitating efficient collaboration between geographically distributed medical teams in planning complex cases. Conclusions: The integration of this quality management and secure transfer tool represents an essential step towards a modern e-Health infrastructure. The solution is vital for reducing response times in neurosurgical emergencies, strengthening the continuity of medical care, and improving patient care in medical institutions such as Bacău County Emergency Hospital.

KEYWORDS: Neurosurgical Workflow Optimisation, Secure Data Transmission, DICOM Interoperability, Image Quality Assurance, Telemedicine.

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1. INTRODUCTION

In the current context of accelerated digitalisation in the healthcare sector, this paper aims to address the specific challenges of managing and standardising neurosurgical imaging data at Bacău County Emergency Hospital. This initiative is crucial, given the vital importance of rapid and secure access to imaging information for diagnosis and emergency surgical interventions [1]. The continuous development of non-conventional medical technologies and integrated imaging systems, such as PACS, underscores the need for standardised and secure protocols for data transfer and management, which are essential for supporting clinical decision-making and precision intraoperative navigation [2]. Thus, implementing a system that integrates these technologies is essential to promote therapeutic success, patient safety, and data security [2].

1.1 General Context of Digitalisation in Healthcare

The digital era has profoundly transformed numerous sectors, and the healthcare field is no exception, becoming an essential pillar of modern medical infrastructure. Accelerated digitalisation aims to optimise processes, improve care quality, and increase the accessibility of medical services [3]. In this context, rapid and secure access to medical data becomes critical, especially in neurosurgery, where every second can significantly influence the patient's prognosis. Informational fragmentation, data silos, and the lack of interoperability among various medical IT systems remain significant challenges at the national level [4], [5], [6], [7], [8].

Current trends in telemedicine and teleradiology underscore the stringent need for efficient data exchange solutions. Telemedicine, defined as the provision of remote medical services through information and communication technologies, has experienced rapid expansion and is essential for multidisciplinary consultations and for ensuring continuity of care, especially in isolated areas or during crisis situations [9]. Teleradiology, as a subdomain of telemedicine, enables the interpretation of medical images by remotely located radiologists and neurosurgeons, accelerating diagnosis and therapeutic planning, which are vital to clinical workflow efficiency. These developments necessitate robust data transmission and management systems that ensure data integrity, confidentiality, and availability [10].

1.2 The Importance of Neurosurgery in the Context of Bacău County Emergency Hospital

Neurosurgery is an extremely complex medical speciality, in which the precision of diagnosis and surgical interventions has a direct and often definitive impact on the patient's quality of life. Within Bacău County Emergency Hospital, neurosurgery plays a strategic role for the region, managing a significant volume of complex cases ranging from traumatic emergencies to tumoral pathologies and vertebral conditions. The healthcare facility is the only one in the county capable of resolving neurosurgical emergencies. It also represents the sole healthcare unit in the centre of the northwest region that can provide neurosurgical emergency services within a 150 km radius of this facility. Like other large-scale medical institutions, the hospital faces the constant need to optimise workflows and integrate advanced technologies to meet growing patient demands and ensure high care standards. The regional context of Bacău County Emergency Hospital highlights the necessity for a high-performance digital infrastructure capable of supporting multidisciplinary collaboration and remote specialist consultations.

1.3 Motivation of the Study

Despite technological advancements, medical practice at Bacău County Emergency Hospital has highlighted significant limitations of traditional neurosurgical imaging data transfer methods. Reliance on physical media, such as CDs/DVDs, introduces considerable delays, risk of data deterioration, and compatibility issues. Moreover, the use of unsecured platforms for exchanging sensitive information, although fast, severely compromises patient data confidentiality and integrity, contravening strict data protection regulations [11]. These shortcomings are exacerbated by the increasingly pressing need for remote multidisciplinary consultations, where rapid, secure access to high-fidelity imaging is essential for obtaining specialised medical opinions and planning complex cases. The absence of a standardised and secure imaging data transfer system leads to operational inefficiencies, prolongs diagnostic times, and consequently delays the initiation of appropriate treatment, negatively impacting clinical outcomes [1]. These major challenges form the central motivation of the present work. Therefore, the study proposes to address these gaps through an integrated IT solution that enables rapid, secure access to DICOM images, thereby improving decision-making processes and optimising neurosurgical patient care [2], [12].

1.4 Objectives of the Paper

Starting from the identified challenges, the paper sets an ambitious general objective: Creating a secure digital ecosystem for the standardised management and exchange of neurosurgical imaging data. This ecosystem aims to overcome the limitations of existing infrastructures and facilitate efficient collaboration between different medical units.

By fulfilling these objectives, the paper contributes to strengthening a modern e-Health infrastructure, essential for improving the quality of patient care in neurosurgery.

Table 1. To achieve this general objective, the following specific objectives have been established (Sources: Author's personal contribution).

No.	Specific objectives	Description
1	Removing Physical Media	Develop an IT solution that completely replaces the dependence on CD/DVDs and other physical storage media, thus optimizing operational flow and reducing the risks associated with manual data management.
2	Reduction of diagnostic time	Ensuring instant and high-fidelity access to neurosurgical images, making it easier to quickly obtain a second medical opinion and significantly shortening the time needed to establish diagnosis and plan interventions.
3	Data security	Implementation of advanced encryption algorithms and strict security protocols to guarantee the confidentiality, integrity and availability of imaging data throughout the transfer and storage process, in accordance with the legal and ethical standards in force.

2. LITERATURE REVIEW

2.1 Standards in Medical Imaging

The digitalisation of medical imaging has revolutionised diagnosis and treatment, facilitating rapid access to essential visual information. The foundation of this digitalisation is standardisation, and in this context, three components play a central role: the DICOM protocol and the PACS and RIS systems.

The DICOM protocol is the global de facto standard for managing, storing, printing, and transmitting medical imaging information in medicine [13]. Owned by NEMA, the current DICOM3 version enables the interconnection of medical equipment from different manufacturers, such as CT, MRI, and PET scanners, with servers, post-processing workstations, printers, and networks, providing a universal imaging "language" [2]. It specifies a non-proprietary data interchange protocol, a digital image format, and a file structure for biomedical images and associated information, addressing five general areas of application: network image management, image interpretation management, print management, imaging procedure management, and offline storage management [14]. By uniformly structuring imaging data and associated metadata, DICOM enables seamless communication and interoperability among various imaging modalities, archiving systems, and radiology information systems [13].

PACS and RIS systems are complementary and essential components of radiological workflow management. The PACS revolutionises the way images are stored, distributed, and accessed, providing efficient image management, rapid and secure access to patient data, and considerably simplifying the diagnostic and treatment planning process [2]. By integrating with neuronavigation systems, PACS enables rapid extraction of detailed, relevant images from the database, facilitating more precise preoperative planning in neurosurgery [2]. The RIS, on the other hand, is an information system that manages administrative and clinical processes in a radiology department, from patient scheduling and demographic data recording to the management of investigation results. The integration of PACS with RIS and the Hospital Information System is crucial to ensure data coherence and streamline workflow, though it may pose challenges in maintaining data consistency and compatibility across heterogeneous components [15], [16].

2.2 Challenges in the Interoperability of Medical Systems

Although standards such as DICOM have significantly contributed to image exchange, full interoperability between medical systems remains a major challenge. This is primarily due to compatibility issues across heterogeneous systems and metadata quality [17], [18].

Healthcare systems utilise a multitude of heterogeneous data models with varied structures, terminologies, and coding systems, making direct data mapping difficult [17]. Many medical organisations operate with "legacy" systems featuring limited connectivity options, complicating modernisation efforts. Even with standardisation efforts, multiple competing or overlapping standards continue to fragment the ecosystem [19]. This heterogeneity is also highlighted by the difficulty of exchanging or transferring data between competing platforms [20]. A significant concern is the interoperability of portable medical devices, which requires a system capable of transferring data both one-to-one and one-to-many, with extensive device compatibility [21].

Metadata plays a crucial role in medical imaging, providing the context needed for accurate interpretation. However, there are significant challenges related to the quality and standardisation of metadata. The DICOM specification, for example, is complex and allows considerable variability across manufacturers in how customised data is incorporated into DICOM headers, which may require expertise for data conversion [20]. Inconsistencies in data application, the lack of formal methodologies for modelling data elements and messages, and the absence of clear roles for applications and users contribute to interoperability problems [18]. Metadata quality can be affected by incomplete, duplicate, or inaccurate data, leading to difficulties in finding images and diagnostic errors [22]. These aspects underline the need to define a unified, complete, and standardised model for medical imaging metadata [23].

2.3 Medical Data Security

The processing of medical data in electronic format poses numerous challenges related to resource security and patient confidentiality [11]. The healthcare environment faces increasing cyber risks, and regulations such as GDPR impose strict requirements for protecting this sensitive information.

The General Data Protection Regulation, implemented in Europe in 2018, governs the confidentiality of user data across multiple sectors, including healthcare. GDPR requires healthcare entities to obtain users' consent before collecting, processing, and sharing patients' data [24]. It establishes technical security measures for hosting sensitive patient data, including facility access controls, policies for workstation use, electronic media, and all processes for the transfer, removal, destruction, and reuse of electronic information [25]. Biometric, genetic, and protected health information are classified as sensitive data and require explicit consent for processing [26]. In Romania, alongside GDPR, there are national laws such as Law no. 46/2003 on patients' rights and Law no. 95/2006 on healthcare reform, which define patients' rights regarding the confidentiality of medical information and the responsibilities of medical service providers [27]. Transfers of personal data to third countries or international organisations are major subjects within European legislation, requiring security and confidentiality mechanisms [28].

Health information systems are vulnerable to various cyber threats, and a flawed design of medical devices that fails to account for them can lead to what is known as "technical debt" [21]. Data confidentiality is a major concern in the medical field, as medical information is considered highly private and access must be strictly authorised [21]. Breaches of confidentiality can have serious consequences for patients and lead to legal sanctions, financial losses, and reputational damage for service providers [21]. Therefore, information access control is a major constraint on ensuring data confidentiality and security, necessitating access segmentation across the entire system [21]. Additionally, health data must be audited regularly to ensure its integrity and consistency [21]. Ensuring data integrity in a health information system ensures data correctness, minimises errors, and improves patient safety [21].

3. METHODOLOGY

3.1 Study Design

The present research adopts a retrospective analytical study design, focusing on evaluating existing neurosurgical imaging data flows and analysing the impact of implementing a dedicated IT solution at Bacău County Emergency Hospital. The study aimed to thoroughly understand the limitations of the previous medical image management system and quantify the benefits of the new solution.

Analysis period and data selection criteria: The retrospective analysis covered the period from 2017 to 2025, enabling an evaluation of the evolution of data flows. The data selection criteria included:

- All neurosurgical imaging data is generated and transferred at SJU Bacău.
- Records regarding transfer times and waiting times for medical consultations involving imaging.
- Incidents related to data integrity or security, as well as qualitative feedback from medical staff.
- The data were anonymised in accordance with GDPR regulations to ensure patient confidentiality.

3.2 Analysis of the Initial Situation at SJU Bacău

Before implementing the IT solution, SJU Bacău faced a neurosurgical imaging data management system characterised by significant operational inefficiencies and vulnerabilities in information security.

The workflow predominantly relied on physical media for transferring medical images between departments or to other institutions for multidisciplinary consultations. Alternatively, in emergency situations, unsecured methods such as messaging apps or personal email were often used to accelerate the process. These methods resulted in considerable waiting times of 2 to 12 hours to obtain a second medical opinion, which directly affected the timeliness of diagnosis and treatment initiation [1].

Table 2. Analysis of the previous workflow identified several critical points (Sources: Author's personal contribution).

No.	Critical points identified	Description
1	*Data transfer latency*	The physical process of requesting CT/MRI exploration. Imaging evaluation and writing/reading on CD/DVD. Transporting them significantly delayed access to images and making a medical decision.
2	*Security vulnerabilities*	The use of insecure platforms exposed patient data to cyber risks and privacy breaches.
3	*Compatibility issues*	CDs/DVDs could be unusable or incompatible with certain visualization systems in the neurosurgery department.
4	*Lack of interoperability*	Inability to automatically integrate imaging data with existing PACS/RIS systems, requiring time-consuming manual interventions.
5	*Data corruption*	Risk of loss or alteration of data on physical media.

These limitations highlighted the need for a substantial technological intervention to optimise data flows.

3.3 Architecture of the Proposed IT Solution

The proposed IT solution, named the PIXELDATA platform, was designed as an integrated digital ecosystem, with the primary objective of standardising, securing, and optimising the exchange of neurosurgical imaging data. This platform enables the transfer, storage, and visualisation of medical images while simultaneously ensuring their real-time quality management. Its modular architecture facilitates integration with the hospital's existing systems and ensures scalability, designed to handle large volumes of imaging data and support many users and concurrent operations. The PIXELDATA platform's structure is robust, designed to ensure constant data availability and minimise latency in accessing it, a critical aspect in medical emergencies.

Algorithms used:

- Encryption methods for security: To ensure the confidentiality and integrity of data during transfer and storage within the PIXELDATA platform, advanced encryption algorithms have been implemented. This approach guarantees that the data is protected against unauthorised access and illicit modifications, in compliance with the strict requirements imposed by regulations such as the GDPR [24]. Security is a primary concern in medical systems, where data breaches can have serious consequences [21]. Some approaches involve pixel-level encryption or XOR operations to enhance data protection and prevent disclosure in cloud environments [29].
- Lossless compression techniques for image integrity: To reduce the volume of data transmitted and stored by the PIXELDATA platform without compromising the imaging quality required for diagnosis, the solution implements lossless compression. These methods, such as Run-Length Encoding compression or JPEG Lossless, allow the perfect reconstruction of the original image at the pixel level, ensuring that imaging integrity is fully preserved for diagnostic and surgical purposes [30]. The specialised literature indicates that a compression ratio of 5-10:1 can be achieved without loss of detail, which is essential in medical imaging [31]. These techniques ensure that the data can be extracted exactly as they were initially, without modification [32].

A crucial aspect of the PIXELDATA platform is the intelligent management of DICOM metadata. The solution includes functionality for validating and automatically correcting DICOM tags. This process involves:

- Compliance verification: The platform automatically validates whether DICOM tags comply with the DICOM standard, identifying missing or incorrect fields [2].
- Automatic/assisted correction: In the event of identifying errors or inconsistencies, the system attempts automatic correction or signals the need for manual intervention, ensuring superior metadata quality [23]. Automatic extraction of information from DICOM headers and validation of the scanning protocol contribute to metadata accuracy [32]. This approach ensures efficient interoperability between heterogeneous PACS systems, facilitating the exchange of structured and contextual data necessary for precise interpretation.

3.4 Implementation in the Clinical Environment

The implementation of the PIXELDATA platform at SJU Bacău was a phased process, carried out in the second half of 2024. Designed to minimise operational disruptions and maximise adoption by medical staff, this system connects the Radiology department, the Neurosurgery section, and more, via an IT network. This process involved close collaboration between IT teams, clinicians, and system providers [33].

The PIXELDATA platform was integrated with the existing IT infrastructure of SJU Bacău, particularly with the PACS and RIS systems, without, however, also connecting to the Electronic Health Record [2], [34]. This integration involved developing interfaces and APIs compliant with DICOM and HL7 standards to enable bidirectional, secure communication and data exchange between platforms [35]. The goal was for images transferred through the new solution to be directly accessible from PACS. An efficient integration ensures an automated workflow, minimising medical staff response times and improving efficiency [36].

A key element of the success of the PIXELDATA platform implementation was the intensive training program, adapted to the specific needs of different categories of personnel [33]. These sessions covered:

- Use of the solution's interface for transferring and remotely viewing images.
- Standardised operating procedures, including aspects related to data security and GDPR compliance.
- Benefits provided by the new solution within the existing workflow.

The training was accompanied by continuous technical support and feedback sessions to ensure a smooth transition and rapid adoption of the system by all users [36], [37]. It is well known that active user involvement and continuous technical support are crucial for overcoming resistance to change and fully realising the potential of a new technology in the clinical environment [38].

The platform provides access to the desktop version of the imaging taken at the Bacău County Emergency Hospital.

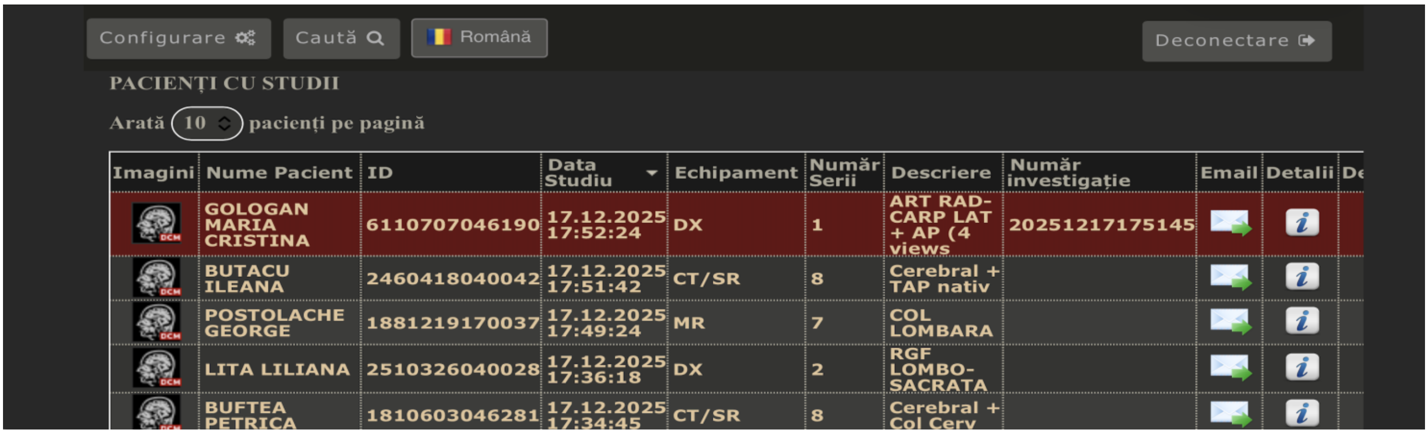

Figure 1. Summary view of the access screen through the PixelData platform (Sources: SJU Bacău medical imaging database).

4. RESULTS

The analysis of the results obtained following the implementation of the IT solution for standardising neurosurgical imaging at Bacău County Emergency Hospital, in accordance with the previously described methodology, demonstrates the transformative impact of the proposed digital ecosystem on workflows, technical performance, medical decision-making, and user satisfaction.

4.1 Comparative Analysis of Workflows

The implementation of the IT solution resulted in significant workflow optimisation in the neurosurgery department at SJU Bacău, as evidenced by the elimination of time-consuming steps and increased overall efficiency.

The comparative analysis of average data processing and transfer times indicated a drastic reduction in the period required from the moment of performing an imaging investigation until its visualisation by the neurosurgeon. Previously, reliance on physical media and unsecured transfer methods resulted in delays of hours or even days in obtaining a second medical opinion [1], whereas the implemented solution enabled instantaneous access to high-fidelity imaging. This substantial reduction in latency was crucial, especially in emergency cases, where rapid diagnosis and surgical intervention planning are essential for saving the patient's life and minimising neurological sequelae.

A fundamental result of the implementation was the complete elimination of dependence on physical media for the transfer and archiving of medical images. This transition resolved multiple problems previously encountered:

- Compatibility issues: No further cases of data unreadability due to software or hardware incompatibility have been recorded.
- Risk of damage/loss: The physical risk of data deterioration or loss has been eliminated.
- Operational costs: Costs associated with the acquisition, inscription, and management of physical media have been reduced.

Through this elimination, the image management process has become more streamlined, reliable, and cost-effective, thereby contributing to the creation of a robust digital ecosystem as proposed in the paper's objectives.

4.2 Technical Performance Evaluation

The technical performance evaluation of the IT solution demonstrated that the proposed architecture meets the speed, quality, and interoperability criteria required for a demanding clinical environment.

The solution achieved average transfer speeds superior to previous methods, enabling the upload and download of complex imaging studies within a significantly reduced timeframe. Latency in accessing images, even for geographically distributed users, was minimised, enabling rapid, efficient consultations. This performance is partly due to optimised network protocols and efficient compression techniques.

The use of lossless compression algorithms ensured the maintenance of absolute fidelity of medical images. Any imaging study transferred through the solution could be viewed with the same diagnostic quality as the original image, without artefacts or resolution degradations. This guarantee of image integrity is crucial in neurosurgery, where minimal details can have major implications for diagnosis and surgical planning.

The solution demonstrated a high interoperability success rate with existing PACS systems, particularly at the internal level within SJU Bacău. The validation and automatic DICOM tag correction functionalities proved effective in ensuring metadata compliance and facilitating the seamless integration of imaging studies into diverse heterogeneous IT environments [23]. This interoperability capability was a key factor in creating a functional digital ecosystem.

4.3 Impact on Medical Decision-Making

The most significant impact of the IT solution manifested itself at the level of the medical decision-making process, optimising collaboration and improving the quality of care.

Rapid, secure access to high-fidelity imaging significantly facilitated the acquisition of second medical opinions. Neurosurgeons were able to share complete studies with external specialists, regardless of their geographical location, in real time or near real time. This aspect is vital for complex cases, providing additional perspective and contributing to a more accurate diagnosis and better-founded therapeutic plan.

With quick access to the imaging database and through the mobile component, medical decisions can be made in record time.

Figure 2. Mobile screenshot taken while searching the PixelData database (Sources: SJU Bacău medical imaging database).

Several clinical cases from SJU Bacău have demonstrated the critical role of data transfer speed [2]. In patients with acute craniocerebral trauma, as observed in Figure 3, where rapid neurosurgery is vital, the ability to instantly transfer CT images and obtain a quick decision from the on-call medical team or an external specialist significantly reduces the time to surgery [1], [39]. This reduction in response time had a direct impact on the patient's prognosis, minimising the risks of permanent neurological damage and improving the chances of recovery [1].

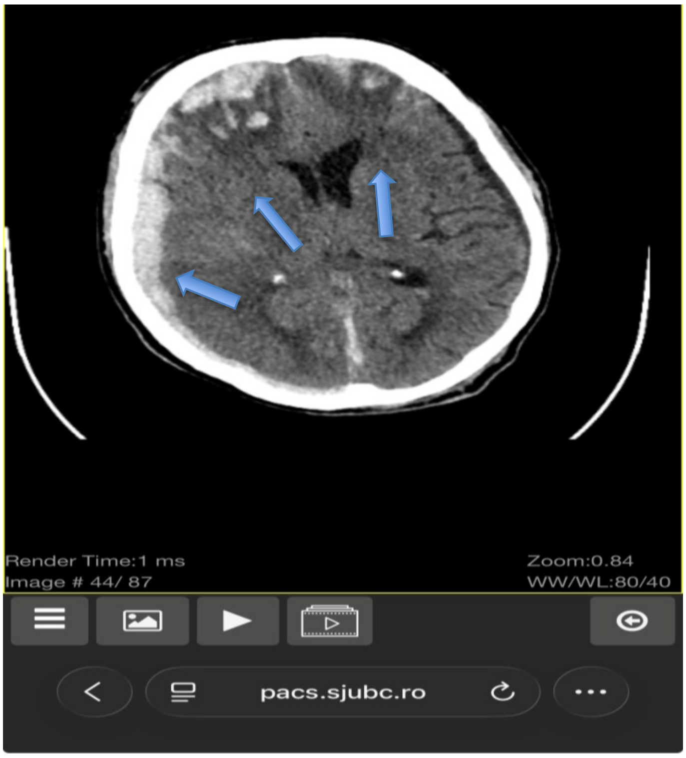

Figure 3. Fig. 1 Native brain CT examination performed on a patient with a head trauma, highlighting multiple brain injuries (Sources: SJU Bacău medical imaging database).

5. DISCUSSION

Following the concrete results obtained after the implementation of the IT solution at SJU Bacău, which demonstrate a drastic reduction in imaging access times [1], the elimination of dependence on physical media, and superior interoperability [2], [23], this section interprets these findings in the broader context of the specialised literature [12], evaluates the significant clinical and administrative benefits [40], and identifies the inherent limitations of the study and the implemented solution [41], [42], thereby contributing to the validation of global trends in digitalisation in neurosurgery.

5.1 Interpretation of the Results in the Context of the Specialised Literature

The PIXELDATA IT solution, implemented at SJU Bacău to standardise neurosurgical imaging, aligns with global digitisation trends and demonstrates the capacity to overcome challenges identified in the specialised literature. The drastic reduction in time from investigation to visualisation and the elimination of dependence on physical media confirm the necessity and efficiency of investments in digital infrastructure, as highlighted by numerous studies regarding the importance of rapid access to data in emergency medicine [1].

Compared to other solutions on the market, the Bacău approach aligns with the fundamental principles of the DICOM standard [2], [13] and PACS systems [2], which are cornerstones of modern medical imaging management. The objective of eliminating physical media was achieved through the integration of a digital platform that fully replaced CDs/DVDs, optimising operational workflows and reducing the risks associated with manual data handling. A major challenge identified in the specialised literature is interoperability between heterogeneous systems and metadata quality [17], [19], [20]. Our solution directly addresses this issue through advanced functionality for validating and automatically correcting DICOM tags [23], a feature that distinguishes the implementation from simpler solutions that may struggle to maintain long-term data coherence [22]. This intelligent metadata approach is crucial to ensure not only data transfer but also their integrability and usability across diverse clinical and archiving systems.

Integration with existing PACS systems demonstrates awareness of "information silos" and compatibility difficulties [6], [7]. The interoperability success at SJU Bacău validates the efforts to develop interfaces and APIs compliant with DICOM and HL7 standards, demonstrating a direction similar to that of other studies proposing solutions to improve data exchange in complex environments [18]. This directly reduces diagnostic time by ensuring instant, high-fidelity access to neurosurgical images, facilitating the rapid acquisition of a second medical opinion. In addition, securing data through advanced encryption algorithms, in compliance with GDPR regulations [24], positions the PIXELDATA solution among modern systems that prioritise the confidentiality and integrity of medical information.

5.2 Clinical and Administrative Benefits

The implementation of the PIXELDATA IT solution at SJU Bacău generated significant benefits at both the clinical and administrative levels, surpassing mere technological improvement and contributing to a holistic optimisation of processes, in accordance with the objectives of the study.

By eliminating physical media, direct reductions in administrative costs were achieved for the acquisition, burning, labelling, transportation, and archiving of CDs/DVDs. The streamlining of working hours for medical and administrative staff, enabled by rapid access to images, optimised human resources. Furthermore, reducing diagnostic time during emergencies enables more efficient utilisation of hospital resources, including operating rooms and expensive equipment, thereby maximising treatment capacity and return on investment. Although the study did not precisely quantify these savings, the alignment with the specialised literature indicates that digitising workflows enhances efficiency and long-term cost optimisation [43], [44].

The greatest benefits are seen in the quality of care and patient safety, which are directly linked to the objectives of reducing diagnostic time and ensuring data security. Instant access to high-fidelity imaging, secured by advanced encryption algorithms [24], significantly reduces the risk of diagnostic and treatment errors. The ability to quickly obtain a second medical opinion facilitates complex clinical decisions and contributes to a more precise therapeutic plan, significantly shortening the time required to establish the diagnosis and plan interventions. In neurosurgical emergency cases, where time is a critical factor, reducing data transfer latency directly impacts patient prognosis, minimising sequelae and improving postoperative outcomes. This approach is fully in line with the general objectives of digitalisation in healthcare, which aim to improve the quality of care and patient safety by optimising access to information [21].

5.3 Limitations of the Study and the Implemented Solution

Although the results are promising, it is essential to acknowledge the study's limitations and the implemented solution to contextualise the findings and identify future directions. These limitations may influence the complete achievement of all the objectives of the work.

Although the PIXELDATA solution has demonstrated a high interoperability success rate, complete integration with all external, heterogeneous medical systems remains an ongoing challenge due to the diversity of standards and software versions. Maintaining compatibility and adapting to new DICOM versions or other standards requires continuous investments in development and maintenance [20]. This can, to some extent, affect the reduction in diagnostic time across the entire regional medical ecosystem if partners lack compatible infrastructure. Another aspect is the dependence on network infrastructure; high latency in external networks can impair the transfer performance of very large images, thereby limiting the efficiency of achieving the objectives of speed and accessibility.

A limitation of the retrospective study is the lack of a direct control group, which could have provided a more rigorous basis for quantifying the benefits of reducing diagnostic time. Additionally, the long-term impact on costs and clinical outcomes requires continuous monitoring and a longitudinal study to fully validate the return on investment and success in achieving the objectives of resource optimisation. Nevertheless, the positive user feedback and the immediate impact on operational efficiency and decision-making underscore the solution's intrinsic value, despite the limitations.

6. CONCLUSIONS

6.1 Summary of the Main Conclusions

The present study investigated and demonstrated the effectiveness of implementing the PIXELDATA IT solution in standardising and optimising neurosurgical imaging data workflows at Bacău County Emergency Hospital. The overarching objective of creating a secure digital ecosystem for managing and standardising the exchange of neurosurgical imaging data was achieved by fulfilling the formulated specific objectives.

By implementing the PIXELDATA platform, a drastic reduction in the time from the completion of the investigation to the neurosurgeon's visualisation of the images was demonstrated. This is crucial in neurosurgery, where short response times can significantly influence the patient's prognosis [1]. The solution's capacity to provide instant, secure access to high-fidelity images facilitated the rapid acquisition of a second medical opinion and accelerated diagnostic and intervention planning, directly contributing to improved medical care quality and patient safety.

In addition, the specific objectives of the work were successfully achieved:

- Elimination of physical media: The PIXELDATA platform has largely eliminated the need for CDs/DVDs for image transfer and archiving at SJU Bacău, optimising the operational workflow and reducing risks associated with manual data management.
- Reduction of diagnostic time: Instant and high-fidelity access to neurosurgical images has significantly shortened the time required to establish the diagnosis and plan interventions, including by facilitating rapid access to specialised medical opinions.
- Data security: By implementing advanced encryption algorithms and strict security protocols, the PIXELDATA platform has ensured the confidentiality, integrity, and availability of imaging data throughout transfer and storage, in accordance with current legal and ethical standards, including GDPR [24]. Intelligent management of DICOM metadata has ensured interoperability and data quality [23].

The success of implementing the PIXELDATA IT solution at SJU Bacău and the validated benefits open broad prospects for its extension and scaling, with necessary adjustments to address the remaining challenges.

The modular architecture and interoperability capabilities of the PIXELDATA platform make it an ideal candidate for extension to all hospitals in Bacău County. Implementing such a solution at the regional level would strengthen a unified digital ecosystem, enabling centralised and standardised management of all imaging data. This extension would facilitate the secure and efficient exchange of imaging data between institutions, support the concepts of teleradiology and telemedicine, and ensure continuity of care at scale, especially for patients from medical units without specialised neurosurgery services who require consultation at SJU Bacău.

Although a significant reduction in reliance on physical media was achieved at SJU Bacău, the study highlighted that the use of CDs/DVDs could not be eliminated, particularly for patients examined in other medical units outside the PIXELDATA system but who benefit from specialised neurosurgery services at SJU Bacău.

To overcome these limitations and maximise the benefits of a regional platform, we recommend the following:

Table 3. Recommendations for a regional platform (Sources: Author's personal contribution).

No.	Proposals	Description
1	Extension of integration	Prioritising the integration of the PIXELDATA platform with the IT systems of partner hospitals in the county, to enable direct and secure transfer of images, eliminating the need for CDs/DVDs.
2	Alternative solutions for non-integrated units	Developing and implementing secure upload solutions on the PIXELDATA platform for medical units that cannot be fully integrated immediately, facilitating the digitisation of data received on physical media.
3	Awareness and training programs	Continuing and expanding regional training and awareness programs to accelerate solution adoption and minimise resistance to change among medical staff in all involved institutions.

Through these extension and development efforts, the PIXELDATA IT solution can become a model of best practices in the digitalisation of health systems, contributing to the construction of a modern and resilient e-Health infrastructure in Bacău County and, potentially, at the national level. Such initiatives represent an essential step towards the medicine of the future, in which technological precision and efficiency directly contribute to improving population health and patient safety [2].

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