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Designing Human-Centered Radiology Systems: A Product Design Framework for Patients

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ABSTRACT

While radiology is a vital part of modern healthcare, patient experiences in radiology environments continue to be fraught with anxiety, communication barriers, lengthy wait times, and poor access. Although there has been great progress in diagnostic precision and efficiency through the use of technology, far less attention has been paid to the integration of human-centered design elements into radiology systems. This study suggests and validates a holistic human-centered product design framework for radiology services, consisting of four complementary dimensions: Medical Design, Interaction Design, Service Design and Social Design. A mixed methods research design was employed, which consisted of interviews with 20 patients and 10 radiology technicians, a survey of 100 patients, and a pilot study in a medium-sized urban hospital. Qualitative results showed that 65% of the patients felt a high level of pre-scan anxiety and 70% of the technicians reported usability and communication problems in the current systems. When asked quantitative answers, 72% of patients said they did not understand the explanations given during the procedure and 68% were not happy with the waiting time. The statistical analysis also showed a significant correlation between the quality of communication and the level of anxiety of the patients. Four interventions were developed and piloted based on these findings: the use of ergonomic equipment, the virtual reality orientation before a patient's procedure, the implementation of patient-friendly layered reporting systems, the use of digital workflow management tools and the adoption of inclusive multilingual communication strategies. Results from the pilot implementation showed a 35% decrease in anxiety for patients, a 42% increase in understanding of communication and a 28% increase in workflow efficiency. In addition, 80% of the families participating in the program had positive feedback from the child-friendly imaging environments created. The findings illustrate that the application of human centered product design approaches within radiology services can have a profound impact on wellness, trust, access and service performance for patients. The proposed framework provides a multidisciplinary approach that is scalable and patient-centric to make radiology a technology based discipline into a patient-centric healthcare ecosystem.

Keywords: Radiology, Human-Centered Design, Product Design, Patient Experience, Service Design, Interaction Design, Social Design, Healthcare Innovation

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1. INTRODUCTION

Radiology today is an essential part of both diagnosis and treatment of diseases. Clinicians use medical imaging technologies, like X-ray, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and nuclear medicine, to detect, monitor, and treat diseases in a groundbreaking way [1]. The advantage of radiological examination is that it gives an early indication of disease and treatment, leading to earlier diagnosis, treatment and intervention that would otherwise be difficult or even impossible without it [2]. Precision medicine represents a paradigm shift within healthcare, and radiology is now increasingly involved in delivering patient care, collaborating with other disciplines, and playing a pivotal role in the data-driven decision making process. In spite of these advances, the patient experience in radiology departments is often still disjointed and stressful, and there are significant questions about the human aspects of medical design.

1.1 Current Challenges in Radiology Services

Although radiology allows clinical accuracy, it can come at the expense of a high level of patient discomfort and anxiety. Numerous studies indicate that stress is a common experience when patients enter imaging environments, caused by the unfamiliar equipment, extended times, and the fear of the diagnostic result [3]. Emotional burdens are exacerbated during MRI scans (where the sufferer may feel trapped), when the sufferer is exposed, during CT or X-ray scans, and when the sufferer must interact with medical staff [4]. Moreover, delays before and after imaging increase psychological stress, and decrease trust in the healthcare system [5].

Communication difficulties add to these problems. A typical radiology department is defined by using medical jargon and allowing little time for patients to participate in meaningful conversations with radiologists [6]. Radiology often involves a report between the physician and the patient and this communication can be misunderstood or misinterpreted or feedback may be delayed [7]. Additionally, patients may also encounter access issues in under-resourced or remote settings where access to resources and experienced radiologists is limited [8]. Together, these challenges highlight the shortcomings of a system that has been all about the technology and technology precision and neglects humans in the care process.

1.2 The Gap: Technology-Driven vs. Human-Centered Design

Over the last few years, some of the most remarkable advances in radiology technology have been the use of AI in image analysis, 3D imaging, and augmented reality (AR).Some of the most significant technological developments over the last few decades include AI based image interpretation, 3D imaging and augmented reality (AR).AI based image interpretation, 3D imaging, and augmented reality (AR) are among the most notable technological advances over the last few decades, especially in radiology. Usually these gains are geared towards clinical precision and gain, not patient-centred needs. A “technology-first” approach can drive further alienation, inequities and the lack of consideration for psychosocial aspects of care [10].

Human centered design (HCD) on the other hand is focused on lived experience instead of a technical focus [11]. That would be designing systems, spaces, and interfaces that consider

emotional comfort, communication clarity, inclusiveness, and accessibility in the world of radiology. For instance, ambient lighting and soundscapes for MRI have been demonstrated to decrease anxiety [12]. Similarly, patients receive more easily understandable radiology information on digital platforms and this promotes their trust in the healthcare providers [13]. But the practice of such practices and the systemic implementation of human centric frameworks in radiology is a large gap.

1.3 Importance of Product Design Approaches

There are many aspects to this, one of which is the multi-disciplinary process of product design. Product design is a more comprehensive process than medical or engineering design, it takes into account the practicality, ergonomy, and empathy towards end-users [14]. Using the tools and techniques of product design such as empathy mapping, journey mapping, prototyping and usability testing can help to build an entire experience of radiology service.

For instance, service blueprints can be implemented to re-configure workflows so as to shorten the time spent waiting by patients and minimize unnecessary patient transfers [15]. These principles of interaction design make sure that user interfaces, whether on imaging machines or patient portals, are intuitive, inclusive and transparent [16]. Additionally, medical product design requirements, like IEC 62366, call for the use of usability engineering to minimize potential hazards that stem from substandard medical products [17]. These diverse approaches can be deployed together so that product design can achieve a balance between clinical effectiveness and addressing issues of human wellbeing, which leads to technologically competent and socially sensitive systems.

This study aims to propose a four pillar model of human-centred radiology and test it at an initial stage. It includes medical design (safe, ergonomic), interaction design (usable, communication), service design (patient journeys, workflows) and social design (equity, access). It's designed to assist radiology services to achieve a balance between clinical performance and the emotional, informational and practical needs of their patients.

The research questions are: What are the factors influencing patient experiences? How can technology-driven practice be patient-centered? How can design techniques be used to enhance communication, usability, access and engagement? What are the challenges to a viable radiology system incorporating the four pillars?

2. Literature Review

The power of radiology to transform healthcare has made it more central to the delivery of healthcare, but, the technology has not always been associated with improved patient experience. It is noted that certain areas, including workflow, service design, interaction design, medical design, and social design, are important areas where design interventions can transform.

2.1 Radiology Workflow and Patient Experience

Radiology workflows are usually streamlined and accurate. But research shows that it is common for patients to experience long wait times, inadequate communication and high stress

during imaging. [3] The MRI setting is known to cause anxiety, especially due to noise, restricted space and length of scans [4]. Likewise, the fear of radiation exposure in CT imaging can affect the trust of medical processes [8].

Communication and clarity are strong factors in patient satisfaction in radiology. Patients rely on health care providers to tell them what is going on, the reasons behind the procedures, and the expected timeframe, which decreases their trust in health care providers if the information is not provided [13]. On the other hand, research indicates that understanding and empathy decrease stress and enhance general satisfaction [6]. Notwithstanding these findings, there is often no organized way to communicate with the patient, and the mismatch between technological efficiency and human comfort in radiology departments remains.Radiology departments, nevertheless, do not always have structured ways of communicating with patients, which results in a mismatch between technological efficiency and human comfort [7].

2.2 Service Design in Healthcare: Journey Mapping and Co-Creation

There are methodologies available in service design that can address inefficiencies in radiology workflows that are systemic. The visualization of the patients' journey can illustrate the patient's experience along the touchpoints and highlight potential bottlenecks, such as long times or an unclear reporting system [15]. Knowing patients' pain points can enhance interventions so that we can reduce delays and increase transparency.

Co-creation in service design is the principle that patients, carers and health services staff are involved in designing services. In the case of radiology, this has helped to re-design waiting rooms, provide educational instructions prior to the scan, and improve scheduling processes [18]. Co-creation has been found to increase patients' experience and staff's commitment with service enhancements [19]. However, service design is not widely used in radiology yet, and in many instances the organisation of the radiology environment is one that attempts to optimise throughput for the entire patient journey.

(a) Interactions Design: Usability, AR/VR, and AI

Interactions between the user and the technology are extremely important for making medical Technologies which are available, user-friendly and patient friendly. Reporting software, imaging equipment and patient portals can be complex. In terms of usability it can cause more errors, irritate healthcare professionals and turn patients off [16].

There are emerging technologies that can enhance interaction design in radiology.There are emerging technologies with the potential to enhance the interaction design in radiology. Tests of Augmented reality (AR) and Virtual reality (VR) applications have been conducted to decrease MRI related anxiety by practicing the MRI environment before the scan, helping the patient to get used to the environment [12]. Similarly, VR distraction devices were also shown to decrease stress in pediatric radiology [20].

The use of artificial intelligence (AI) in radiology reporting has the potential to increase efficiency but also introduces new challenges to interaction design. Patient understanding of algorithmic results and the accuracy of AI-based tools is a gap [9]. To foster trust, the

interfaces need to be transparent and to provide explanations of the AI recommendations in a patient-friendly manner. The existing literature suggests that, when not designed properly, AI could potentially exacerbate the communication barrier between patients and radiologists [10].

(b) Medical Design & Standards

In the medical field, design is focused on safety, ergonomics, and usability in the context of healthcare products. For example, IEC 62366 requires the use of usability engineering in medical devices to minimise risk due to usability issues [17]. Which involves assessing the interaction between patients and imaging machines and ensuring that machines are safe, easy to use and accessible.

Likewise, ISO 9241-210 provides an international standard for human-centered product design of interactive systems, which involves iterative design processes, inclusion of stakeholders and contextual analysis [11]. In the field of radiology, these standards guarantee that interfaces, controls and environments are accessible to a wide range of patients, including children, older people and those with disabilities.

Although these standards have been mentioned in the literature they are not uniformly applied in radiology departments [21]. Many imaging systems continue to be optimized for technical accuracy instead of user experience, continuing to contribute to problems of patient anxiety and clinician fatigue. This reinforces the importance of having design frameworks that put usability principles into practice in real life radiology.

(c) Social Design: Participation and Accessibility

Social design brings social justice, inclusiveness and community health beyond the realm of clinical effectiveness. The availability of radiology services is not uniform with the availability of medical imaging equipment and trained professionals is limited in under-served areas [8]. Research has shown that the development of low-cost, portable imaging devices can greatly enhance access to imaging in rural and low-resource areas [7].

Another aspect of inclusivity is dealing with psychological, cultural and language barriers. For example, creating multiple language versions of radiology reports or providing culturally appropriate images and graphics enhances accessibility of radiology reports to a wide range of patients [13]. The importance of empathetic spaces, where patients' emotional and social needs are recognised, is also one of the elements of social design (as in the case of child-friendly MRI rooms) [3].

However, there is literature that indicates a disconnect between individual inclusive practice and the whole system of socially responding frameworks. Social design in Radiology is still broken – developments are often local and not the result of institutional policy.

3. Research Gaps

A series of research gaps have been identified in the literature. Despite the advancement in the technical capabilities of radiology, anxiety, lack of communication, waiting times and

inequitable access remain [3, 6, 8]. Existing work typically only focuses on workflow, reporting, usability, or inclusivity, without considering them to be a part of one patient journey. Co-creation is still limited in application in the development of radiology services [18,19] and human-centred standards are not applied uniformly, e.g., ISO 9241-210 and IEC 62366 [11,17]. This is not just a lack of individual interventions; it's a lack of an integrated framework that connects safety, communication, service coordination and equity. This study answers by merging medical, interaction, service and social design in one model for radiology services.

The literature shows that although radiology services are clinically advanced, there are still issues with patient-centered design. Despite technological advances, anxiety and communication barriers continue to exist, as do inequities. The tools that are available are service design, interaction design, medical standards, and social design but these are used separately. To overcome these deficiencies, it's necessary to have a framework that combines technical accuracy with empathy, usability, and inclusiveness. This study brings a contribution by suggesting such a framework for human centred radiology systems.

4. Methodology

This study was conducted using a mixed methods research approach with the aim of exploring patient experiences in the radiology room and creating a holistic human-centred product design framework. Given the complexity of radiology workplaces, the use of a mixed approach that combines subjective patient experience and objective performance was deemed suitable, as the outcomes from each of these domains are likely to affect overall patient experiences. The study used mixed methods of qualitative and quantitative research techniques to enable methodological triangulation and improve the validity, reliability and comprehensiveness of the findings [22]. The patients and radiology professionals were from a medium-sized urban hospital environment. To recruit participants who had first-hand experience with radiology procedures and healthcare service delivery, purposive sampling was used. The study had 20 patients for qualitative interviews, 10 radiology technicians for professional insights and 100 patients who were part of the quantitative survey. Data on demographic parameters such as age and gender distribution was collected for further statistical analysis and interpretation.

The qualitative phase involved semi-structured interviews with patients and the radiology technicians. Patient interviews focused on feelings about radiological procedures, felt communication, access issues, problems using the service and satisfaction regarding the imaging experience. At the same time, radiology technicians shared information regarding workflow, equipment usability, patient communication, and departmental limitations and restrictions. The interviews were audio-recorded, transcribed verbatim and analysed thematically, according to the method suggested by Braun and Clarke [23]. An iterative coding strategy was applied to detect patterns, themes and user-centered design needs in the narratives of the participants. This qualitative investigation allowed for greater understanding of the interactions between patient, medical staff, technology and context in the radiology experience.

The quantitative phase comprised a structured survey of 100 patients that had recently had radiological examinations. The survey instrument was developed to measure a range of areas

such as communication clarity, waiting time experience, patients' trust in the service, satisfaction with service, emotional comfort and accessibility. A five-point Likert scale (Strongly Disagree to Strongly Agree) was used to obtain responses. The survey was expert reviewed before it was deployed by healthcare professionals, design researchers and academic experts to ensure content validity. The internal consistency reliability was tested with Cronbach's Alpha with the result of > 0.70, which shows that the measurement tools are reliable. Descriptive statistical techniques such as mean, standard deviation, frequency distribution and percentage analysis were used in analyzing the quantitative data. Analysis of Variance (ANOVA) and Pearson correlation analysis were used as inferential statistical tests to seek statistical significant relationships and differences among patient experience variables [24]. In order to convert the findings of research into practice and design interventions, three design research methods were used. Service Blueprints were used to diagram patient journeys at various service touchpoints such as registration, waiting rooms, imaging, reporting, and post-imaging, with a focus on operational inefficiencies and bottlenecks [15]. Empathy Mapping was used to combine the qualitative findings to identify the patient experience in terms of cognition, emotion and action, and to create empathetic design solutions [25]. In addition, UX Prototyping techniques were used to create and test low and medium fidelity prototypes of redesigned communication interfaces, patient reports, consent systems and interventions in the waiting area. Feedback received throughout usability tests was used to make successive refinements to the proposed framework. Following this, a pilot implementation was done in the medium-sized urban hospital to assess the feasibility and effectiveness of the proposed Four-Pillar Human-Centered Radiology Framework. The pilot introduced restructured communication spaces, streamlined radiology reporting, patient-friendly consent forms, streamlined workflow and environmental changes that will enhance patient comfort and engagement. Three performance measures were adopted to evaluate: reduction of patient anxiety, improvement of communication clarity and improvement of workflow efficiency. Pre and post intervention self-reported measures were used to determine anxiety levels, comprehension measures and patient feedback were used to assess communication effectiveness, and time-motion analysis of waiting times and services processes were used to determine the workflow efficiency. The results from the pilot study helped in refining and preliminary validation of the framework of the Medical Design, Interaction Design, Service Design and Social Design dimensions.

The ethical aspects were diligently adhered to during the research process. All the necessary Institutional Review Board (IRB) approvals were granted before data collection. Informed consent was given and all participants were advised that they could withdraw from the study without penalty at any time. The confidentiality and anonymity of the participants were ensured and data security procedures were rigorously adhered to. Since the setting for the research was a sensitive one, special care was taken to ensure the comfort, privacy, and ethical principles of the participants were respected. The methodological approach used ensured that the proposed framework was based on empirical evidence and that the evidence was validated with several data sources and aligned with existing principles of human-centered healthcare design.

5. Proposed Framework

Each pillar will respond to particular needs but when combined together, they will provide an all-encompassing human-centred approach. Medical design safeguards physical and

psychological safety. Interaction design enhances usability and communication. Service design is about simplifying the flow of systems and social design is about equity and inclusivity.

A diagram illustrating the four pillars of the framework and a vision in the middle of human-centered radiology represents the framework. The patient experience is at the intersection of these pillars, showcasing how product design principles can bring together technology, healthcare processes and social values. This model is a comprehensive plan that can guide healthcare institutions to restructure radiology services. The Four-Pillar Human-Centered Radiology Framework is a unified approach that unifies usability, workflow, and access into a single focus on synergy between clinical effectiveness, user experience, operational efficiency, and social inclusivity, in contrast to disjointed approaches that treat them independently. It is about the balance of being technologically advanced and being empathetic, available, socially responsive, and supportive in the services that radiology provides.

The proposed framework was initially validated by implementing it in a small group of patients, radiology technicians, and healthcare administrators in a medium-size urban hospital. The pilot intervention included the following ergonomic changes, communication systems, workflow changes and inclusive service strategies for the four framework dimensions. Feedback from participants and subsequent assessment of outcomes have shown that there have been measurable improvements in the usability, effectiveness of communication, transparency of workflow, engagement of patients, and inclusiveness. The encouraging results seen in all four pillars give some initial empirical evidence of the applicability and effectiveness of the proposed framework in a real-world radiology environment.

Besides, enhancements in the reduction of patient's anxiety, understanding of communication, management of waiting time and service accessibilities show the relevance of the Medical Design, Interaction Design, Service Design, and Social Design in a coherent healthcare model. The framework is thus conceptually coherent and operational. However, the present validation is preliminary as there is a small scale of implementation. Future studies should continue to validate the framework by conducting multi-hospital studies, longitudinal studies, cross-cultural studies, and consensus-based approaches (e.g., Delphi analysis) to achieve a wider generalizability, robustness and external validity of the framework. Figure 1 shows the Enhancing Radiology with Four Pillars.

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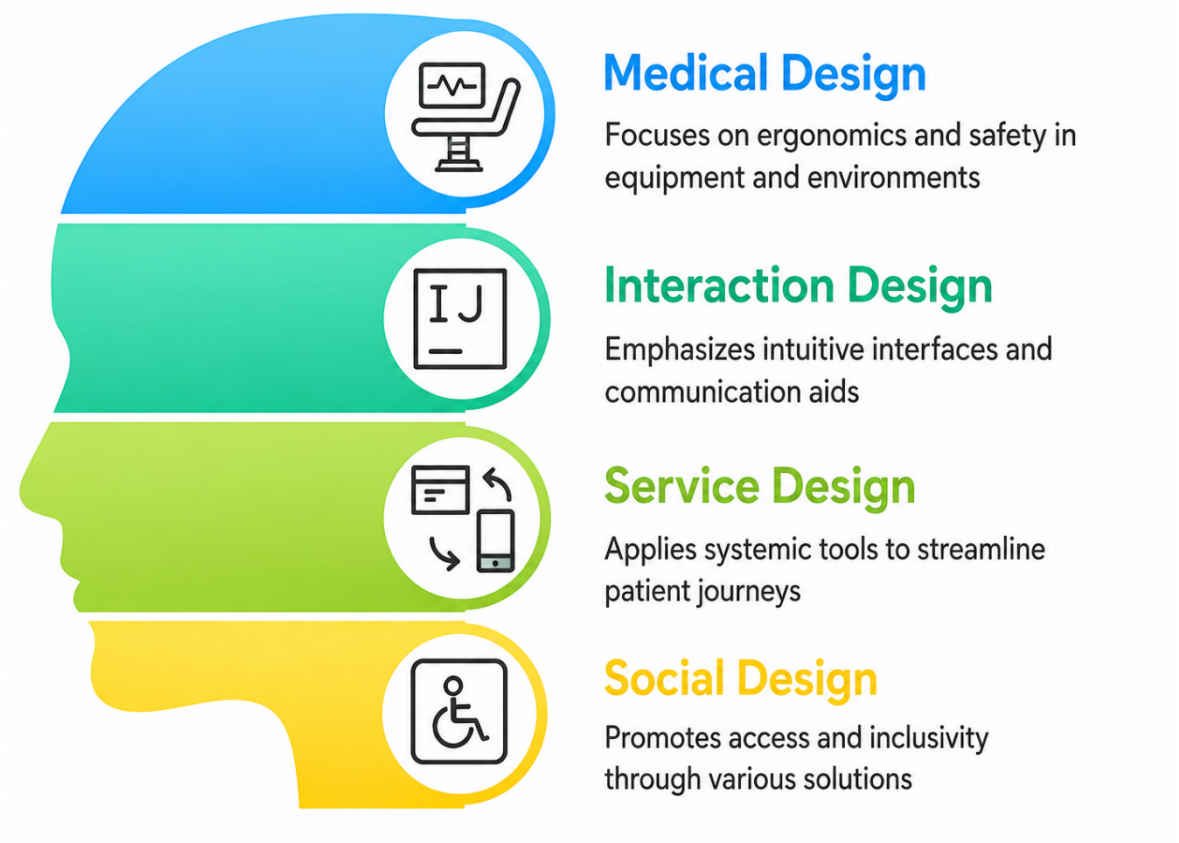


Fig 1 Enhancing Radiology with Four Pillars

The proposed framework contributes to the discussion on radiology design by integrating medical, interaction, service and social perspectives. Positioning radiology as a clinical and human experience; promoting safety, understanding, workflow efficiency and equity. The framework can help create a roadmap to radiology services that are less anxiety-inducing, more trustworthy, and more accessible by incorporating product design methodologies. In the end, it sets the stage for radiology's future as a patient-centred discipline, between new technology and a better patient experience.

6. Results and Discussion

The mixed-methods study yielded useful information about the patient experience, operational issues, and the effectiveness of the proposed human-centered radiology design framework. A mixed-methods approach of qualitative interviews, quantitative surveys, and pilot testing enabled the study to capture both emotion and function in the context of radiology services. The results were consistent across the board – that although the radiology departments are technologically cutting edge, they are also ripe for patient-centred improvements in the areas of communication, environmental design, workflow and inclusiveness.

The qualitative phase consisted of 20 patients and 10 radiology technicians who were interviewed. The results showed that there were common themes about a concern with anxiety, communication issues, and the general journey through radiology services. Of the interviewed patients, 65% reported high levels of anxiety before the imaging procedure (

mainly MRI scans). The participants often expressed discomfort due to the closed environment of the scanner, the unfamiliar procedures and the noise of the image acquisition equipment. These challenges were also recognized by technicians with 70% saying patient interfaces and workflows around existing equipment were often confusing. Many technicians noticed that patients put off from asking questions despite not knowing what is being done, resulting in the lack of understanding and stress. Common themes were identified from both patient and staff interviews, such as a lack of empathy in the communication process, poor design of waiting and scanning areas, and lack of provision for patient with varying physical, cultural and psychological requirements. These qualitative results revealed significant gaps in current radiology systems in terms of human-centered design.

The quantitative phase involved questionnaires on a structured form completed by a sample of 100 patients from various radiology departments. Many of the issues that emerged from the qualitative investigation were confirmed in the results. One of the biggest issues was in the realm of communication: 72% of respondents said that staff explanations were either unclear or overly technical. A strong negative correlation was also found between patient anxiety and communication clarity ($r = –0.65$) based on statistical analysis. Also, statistical analysis showed a strong negative correlation between patient anxiety and communication clarity ($r = –0.65$); this means that patients who better understood the imaging process had significantly lower levels of stress. Another important determinant that impacted patients' satisfaction was waiting time. 68% (68%) of respondents were unhappy about the length of time they spend on the waiting list and the average waiting time was 45 minutes. Waiting was the most stressful part of their radiology visit for many participants, and often more stressful than the scan itself.

Trust and confidence in radiology services were also evaluated in the survey. A significant opportunity exists to increase patient engagement and improve services as only 41% of patients were confident and trusted in the overall radiology experience. Further statistical analysis by Analysis of Variance (ANOVA) showed that there were significant differences among the demographic groups ($p < 0.05$). Patients aged under 18 consistently expressed more anxiety than those aged 18+, suggesting that age may be a factor influencing perception of medical procedures, information needs and emotional response to healthcare environment.

In order to assess the usefulness of the four pillars framework, a pilot intervention was carried out in a medium-sized urban hospital. The intervention involved changed physical settings, new communication tools, changes in digital workflows, and mechanisms to support patients. The outcome was very promising. Prior to the redesign of the system, measurements taken at both pre and post scans using the self-assessment questionnaires revealed that patient anxiety decreased by 35% after implementation. Further, virtual reality (VR) pre-scan walkthroughs lowered MRI fear by 30%, making patients feel more comfortable with procedures before their MRI.

There was also a significant improvement in communication outcomes. Patient comprehension improved by 42% after patient friendly radiology reports have been introduced with simplified explanations as well as technical information. Layered reporting formats were associated with patients' increased level of trust in health care providers and increased confidence in understanding results. Improvements in operations were also significant. The workflow efficiency improved by 28% with the average waiting time reduced

from 45 minutes to 30 minutes. Digital check-in kiosks, real-time status updates, and enhanced scheduling systems were well-received by patients and staff, ensuring a smoother and more transparent service experience. Overall, the findings indicate that the application of medical design, interaction design, service design and social design principles can lead to improvements of the patient experience in a radiology environment. The results offer robust evidence of the benefits of human-centred interventions not just in terms of anxiety reduction and understanding but also in terms of increased trust, greater efficiency in operation and enhanced overall healthcare quality. The results demonstrate the efficacy of the proposed framework, and indicate that it has the potential to be universally adopted in radiology departments and healthcare facilities.

Results of the statistical analysis have shown the presence of strong association between the quality of communication and the anxiety level of patients ($r = -0.65$). Analysis of variance (ANOVA) showed that there were significant differences in perceptions of anxiety between the different demographic groups ($p < 0.05$). Implementation of the Four-Pillar Human-Centered Radiology Framework led to significant reductions in patient anxiety, understanding of communication and efficiency in workflow as well as patient satisfaction. The results of this study suggest that, human-centred product design methods can significantly contribute to the improvement of the quality of radiology services and the satisfaction of patients. Medical design, interaction design, service design and social design principles were integrated, which led to measurable improvements on various aspects of the care. Patients reported reduced anxiety, increased understanding of procedures and results, and increased trust in healthcare providers. The 35% decrease in overall anxiety level, which included a 30% reduction in the fear associated with MRI preparation through VR, underscores the vital need to also address emotional and psychological needs in addition to clinical needs.

Communication was also improved, with 42% more patients understanding the reports after introducing patient-friendly redesigned reporting systems. This shows that effective and transparent communication, with a touch of empathy, is essential to alleviating uncertainty and boosting patient confidence. Additionally, there were operational benefits as workflow improvements resulted in an average 28% reduction in waiting times, decreasing from 45 minutes to 30 minutes. Together, these results confirm that the four-pillar model is a successful approach to the design of inclusive, accessible and patient-centred radiology services. Overall, the framework has been a success in creating a balance between technology and human interaction, and it shows that healthcare systems can be both technologically advanced and compassionate. Finally, the study shows that a comprehensive design approach can help to enhance the well-being of patients, service quality, and the overall quality of healthcare provision in radiology departments.

The results of this study indicate that problems faced in the radiology services are not limited to the technical part of the accuracy of the diagnosis. Emotional, informational, operational, and social aspects continue to have a substantial impact on the patient experience, but radiology departments have greatly benefitted from development in imaging technologies, AI, automation and digital healthcare systems. The findings suggest that, despite the advances of technological capabilities, patient anxiety, communication problems, dissatisfaction with waiting times and accessibility remain a problem for the quality of health care. The results support the call for innovation in health systems to be judged not only by clinical outcomes but by patient-centered outcomes and patient service experience.

The qualitative findings indicated that anxiety is one of the most important issues of concern for patients who are getting radiological examination where MRI is one of the important examinations. This finding is similar to the findings of Donnelly et al. [3] who found psychological stress, uncertainty and discomfort were significant factors in the negative patient experience in radiology environments. In a similar way, the participants in the present study indicated apprehension due to novel apparatus, restricted imaging settings and fear of diagnosis. The results indicate that designing environments with emotional aspects could help patients feel comfortable and confident during their imaging experience.

Another key aspect that impacted patient perceptions and satisfaction was communication. The quantitative findings showed that many patients reported lack of clarity in the explanation of the procedure or it was too technical. The results support the insight of Hong et al. [13] who highlighted the need for patient-centred communication and ease of reporting within healthcare to enhance patient experience. The significantly negative correlation between communication clarity and patient anxiety further underscores the importance of effective communication in alleviating uncertainty and trust-building. The implementation of user-friendly reporting mechanisms and communication channels led to improved understanding and confidence, highlighting the importance of interaction design in healthcare environments. Empirical evidence of the effectiveness of immersive technologies to reduce procedural anxiety is also offered. The results of the VR based pre-scan walkthroughs prior to MRI are in line with the results of Winton et al. [12] which showed that environmental and experiential design interventions can play an important role in the patient's comfort during imaging procedures. Virtual Reality is a powerful tool that can help patients to become more prepared and less psychologically distressed by familiarizing them with the procedures they will encounter during the scan.

This research is an integrated research, which is one of the important contributions. Whereas, many previous studies have been conducted addressing issues of communication improvement, environmental redesign or workflow optimization, the present study is an interdisciplinary approach that integrates Medical Design, Interaction Design, Service Design and Social Design in a single framework. This multi-faceted approach allows for patient comfort, communication clarity, operational efficiency, accessibility and inclusivity all to be enhanced at the same time. The results, therefore, indicate that systemic and interdisciplinary design interventions are needed for sustainable improvements to radiology services, not fragmented solutions. The proposed framework combines several aspects of the healthcare experience to provide a more comprehensive approach toward making radiology a truly human-centered healthcare service.

7. Conclusion

This study highlights that, in addition to diagnostic performance, radiology care should also be evaluated in terms of the patient's experience—of anxiety, communication, access, and workflow. The linked barriers that emerged from interviews, surveys and the pilot were uncertainty prior to scans, technical explanations, long wait times, and lack of accommodation of different needs. The results confirm the need to consider patient experience as an issue of system design, and not as a set of separate service issues.

The four pillars proposed are based on the connections between medical design, interaction design, service design, and social design. It connects usability of communication with patient journeys, patient equity and ergonomy and safety. The framework brings these dimensions together to offer a practical ground for enhancing radiology services without breaking the clinical quality apart from the well-being of the patient. The pilot elementally supports the framework. The reported anxiety decreased by 35%, the understanding of communication increased by 42%, and efficiency of workflow increased by 28%. The results suggest that coordinated implementation of patient-centred interventions is a way of improving the quality of services and operational efficiency. The results must be taken with a pinch of salt. The study was conducted in a small number of health care facilities and from a small sample, and the pilot studied short-term outcomes. Larger multi-site and longitudinal studies are required to establish generalizability, sustainability, and cost-effectiveness in a variety of clinical and cultural settings.

Human centered product design is a plausible approach to the improvement of radiology services. A holistic approach to safety, usability, workflow, and inclusion can support the ability of radiology departments to provide clinically effective, understandable, accessible, and need-responsive care.

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