Alruwaili *et al. BMC Health Services Research* (2024) 24:1327
https://doi.org/10.1186/s12913-024-11706-5

BMC Health Services Research

RESEARCH

Open Access

Teleradiology in Saudi Arabia: a national survey and retrospective review of associated MRI reports

Ashwag Rafea Alruwaili[1,2*], Abdulelah Ammash Alshammari[3], Fahad Mithal Alsalhi[4], Sukaina Ahmed Aldamen[5] and Hend Saleh Alamri[1]

Abstract

Background Due to the recent evolution of telecommunications, it is now acknowledged that digital communication provides essential services for remote areas. Teleradiology allows the ability to obtain images at one site, send them over a distance, and view them remotely for diagnostic or consultation purposes.

Aim The highlighted objectives include (a) the added value of the service, (b) user satisfaction, and (c) quality assurance according to global best practices and national quality standards.

Methods This study utilised an eight-part online self-report survey distributed among employees of the Ministry of Health (MOH) who use the national teleradiology platform. The survey sections were designed to gather comprehensive data, including participant demographics, levels of satisfaction with the service, awareness of security measures, communication effectiveness, perceived advantages and disadvantages, quality assurance, technical challenges, IT support, and future perceptions of teleradiology services. Additionally, a total of 212 MRI reports from patients who underwent brain and spine MRI examinations between 2018 and 2020 were collected from the platform to strengthen the analysis.

Results Most survey respondents (78%) were males, with a significant majority (96.2%) affirming that teleradiology sufficiently addresses clinical inquiries. Furthermore, 90% expressed satisfaction with the service, and 93% endorsed the standardization of MR imaging procedures across Ministry of Health (MOH) hospitals. Notably, 92.4% recognised teleradiology as a transformative strategy for healthcare facilities in Saudi Arabia, concurring with its benefits. The analysis of the MRI reports revealed structural inconsistencies; compared with structured templates, the average number of incorporated elements was reduced, and essential elements were frequently absent. Intriguingly, reports delineating normal cases included a higher incidence of clinical impressions relative to those describing abnormalities, yet the latter contained a more comprehensive array of elements. Variability in report composition was correlated with the years of experience of the reporters. Teleradiology users perceived enhancements in the quality of radiological reporting and the daily operational workflow. Nonetheless, certain limitations were identified, necessitating focused improvements by service providers.

*Correspondence:
Ashwag Rafea Alruwaili
ashalruwaili@ksu.edu.sa

Full list of author information is available at the end of the article

Conclusion Despite teleradiology being a subspecialisation, it can reduce the role of local radiologists. Further research is needed on data security, confidentiality, and archiving options, as well as the cost-effectiveness of teleradiology services.

Keywords Teleradiology, Digital communication, Healthcare delivery, Quality assurance, Neuroimaging

Background

Owing to the recent evolution of telecommunications, digital communication can provide essential services to remote areas while maintaining a high-quality standard that improves service delivery. The disparate allocation of specialised treatment resources between rural and urban medical centres coupled with substantial geographical distance result in the need for frequent travel to access specialised or advanced imaging procedures. This situation has led to notable advancements in telehealth. Teleradiology has emerged as one type of this progress, effectively bolstering healthcare delivery to underserved rural regions while addressing challenges associated with geographical barriers and the scarcity of specialised proficiency.

The expression "teleradiology" originates from the fusion of "tele," denoting transmission across distances, and "radiology," which involves utilising medical imaging for disease diagnosis and treatment. Teleradiology is specifically defined as the interpretation of imaging assessments conducted at a location different from the site of the actual examination. It provides the ability to obtain images at one site, send them over a distance, and view them remotely for diagnostic or consultation purposes. The vastly improved capacity of the internet and the speed of transmission have permitted a much wider use of teleradiology, with centres worldwide providing daytime reporting for out-of-hours imaging services in countries in different time zones. The transmission of images between centres is virtually limitless and has proven valuable for centres seeking expert opinions on emergency and problem cases [1].

Low- and middle-income countries (LMICs) are classified on the basis of their economic development, specifically their gross national income (GNI). Studies on teleradiology in these countries emphasize that a significant portion of the population lacks access to basic radiology services. This disparity in access is called the "radiology divide" and is largely due to limited financial and human resources and a lack of appropriate device procurement and planning [2]. India has successfully implemented teleradiology services, which have proven to be cost effective and capable of providing essential 24/7 coverage, particularly in emergency and trauma care settings [3]. Nonetheless, data on the overall reach and effectiveness of these services within the country and concerns regarding the quality of teleradiology services, including images, are limited [4]. One significant challenge in India remains the shortage of trained technicians to support teleradiology workflows, including image acquisition, digitization, and troubleshooting [3]. In contrast, Iran faces challenges related primarily to inadequate technology and infrastructure, such as low bandwidth, resistance to adopting new technologies among healthcare providers and patients, and difficulties in securing sustainable financial resources through government funding [5]. Although these challenges persist in the aforementioned countries, teleradiology has become a mainstream component of radiology practice in the United States. However, its utilization varies across different practice sizes [6]. The UK and Europe have adopted different approaches to addressing language barriers and ensuring regular audits and standardized regulations [7]. The above literature increasingly emphasizes the importance of user-friendly IT solutions and standardized protocols as key recommendations for improving the effectiveness and widespread adoption of teleradiology services.

Radiological images are transmitted to main centres from outlying hospitals in areas of low population density where small radiology departments have proven unsustainable. This ongoing transformation offers benefits, yet it also presents potential risks to data security and the quality of interaction between radiologists and their clinical counterparts [8]. Errors may arise when composing imaging reports owing to the restricted availability of a patient's prior examinations, a feature that has yet to be integrated into teleradiology platforms. Furthermore, data archiving within teleradiology remains restricted or ambiguous for end-users at remote hospitals, potentially resulting in data loss. However, significant patient satisfaction with teleradiology has been documented globally in the Netherlands [9]. The European Society of Radiology (ESR) distinguished between insourcing teleradiology, a service among partners of the same organization, and outsourcing teleradiology, which involves external services [10]. Referring physicians are more satisfied with the local interpretation of radiologic images than with interpretations provided by international counterparts [11]. This was argued in a report by the European Society of Radiology (ESR):

When there is a time difference between geographical zones, teleradiology may become an efficient method of providing rapid reports for emergency work undertaken during hours when no radiologist is available. "There is great demand for cross-border services for focused legislation, adapted price regulation, and a quality assurance framework." With respect to the current state and added value of teleradiology practice, the American College of Radiology (ACR) concluded that "[T]teleradiology is widely spread throughout modern radiology practice. This platform helps[s] tertiary hospitals achieve geographic and after-hours reporting of images while reducing turnaround times."

Teleradiology has enhanced cooperation among radiologists and broadened multispecialty coverage, thus extending access to underserved populations. Nevertheless, ensuring the quality of offsite examinations requires implementing a standardised reporting system. The integration of information technology solutions can assist smaller practices in maximising the advantages of teleradiology. Additional concerns have been documented, suggesting that teleradiology could lead to even less communication between the referring clinician and patients [6]. Teleradiology ergonomics, legal and regulatory considerations, and licensures should be reviewed by both the transmitting and receiving site administrations. Security and privacy are key issues in any medical service, and teleradiology is no exception. Data security, technology reliability, consent, and interprofessional and professional-patient relationships are new concerns in radiological practice and constitute the minimum ethical and professional standards for teleradiological practice.

The present study seeks to provide insights into the recent endeavours of the Saudi Ministry of Health (MOH) concerning the national teleradiology platform that was initiated in May 2018 to cater to remote hospitals. The key objectives of this study are (a) to assess the service's augmented benefits, (b) to gauge user satisfaction, and (c) to evaluate report quality in alignment with global best practices and quality standards. This study aims to pinpoint challenges and opportunities for enhancing overall efficiency, thus optimising the utilization of national teleradiology platform initiatives within the healthcare continuum and increasing the quality of patient care.

Methods

Study Tool

A total of 82 responses were received from 100 users of the teleradiology platform. An online self-report survey was structured into eight sections accompanied by two open-ended questions, as outlined below. Section A, Demographics, included multiple-choice questions that gathered participants' information, including sex, nationality, job location and description, years of experience, hospital size, and payments received for teleradiology services. Section B, Teleradiology services, assessed participants' satisfaction levels with teleradiology services. It covered aspects such as the quality of teleradiology reports on the basis of subspecialty and the payment process. Section C, Service Security Awareness, gauged participants' knowledge of legislation and regulations about teleradiology services and examined information about data sharing, privacy concerns, and the inception of teleradiology. Section D, Communication, examines various aspects of communication, including the communication mechanism among referring physicians, local radiologists, and teleradiologists. It also covered topics such as access to clinical information by teleradiologists and the feasibility of case discussions with teleradiologists. Section E, Perceived Advantages and Disadvantages, considers participants' perspectives regarding the pros and cons of teleradiology services. Section F, Quality Assurance and Control, included details about accessing previous studies and clinical data. It also addressed whether teleradiology services adhered to the quality criteria established by the Saudi Central Board for Accreditation of Healthcare Institutions (CBAHI). Section G, Technical Challenges and IT Support, focuses on technical obstacles and the responsiveness of IT support in resolving issues related to platform access. Finally, Section H, Future Perception, explores participants' outlook on the future of teleradiology.

To conclude, the survey incorporated two open-ended inquiries to capture participants' insights into the future role of teleradiology and their perceptions of the effectiveness of the teleradiology platform within their local hospital. The purpose of the questionnaire was to assess satisfaction levels among beneficiaries, including referring physicians, local radiologists, teleradiologists, and administrative personnel within the medical imaging departments of peripheral hospitals. This online questionnaire was distributed to designated teleradiology users.

Teleradiology reports

A retrospective analysis was performed on 212 magnetic resonance imaging (MRI) reports from patients who underwent examinations via teleradiology between 2018 and 2020. These reports were retrieved from the national teleradiology platform. Data from these reports were meticulously extracted and subsequently organised in Microsoft Excel. The evaluation was conducted by comparing the reports against structured report templates derived from the Radiological Society of North America (RSNA) MRI report templates, which are freely accessible online (http://www.radreport.org/). The RSNA standard templates we utilised were specifically for routine scans, which are widely recognised and provide a consistent framework for reporting. Importantly, more specific structured templates that are tailored to particular diseases are available. These disease-specific templates can offer more detailed guidance when necessary, ensuring that reports are comprehensive and focused on particular clinical conditions. However, we did not utilise these disease-specific templates in this study. The structured nature of these templates is designed to ensure that all necessary information is included in the reports and offers an excellent benchmark for assessing the completeness and quality of radiology reports, which was a central focus of our study. The report templates were designed to provide a systematic and comprehensive approach for reporting various MRI examinations to ensure that the reports included essential information to guide clinical decision-making. These templates prioritised clinically pertinent information, guided the inclusion of modality-specific details, and emphasised contextual insights for comprehensive understanding. Structured reporting elements prompt concise, actionable data presentation, which is vital in time-sensitive scenarios [12].

Statistical analysis

The analysis of the results involved the use of SPSS to calculate frequency distributions and summary statistics. Fisher's exact test was employed in cases with small sample sizes. The Mann–Whitney U test was applied when dealing with ordinal or continuous outcomes, such as element counts without a specific distribution. This test facilitates the comparison of two groups, such as normal and abnormal reports. Additionally, the Fisher–Freeman–Halton test, conducted via the statistical package in R version 4.1.3, was used to assess potential disparities in the sex distribution across distinct and unrelated categories by comparing percentages.

Ethics

This study was approved by the Central Institutional Review Board (IRB) of the Ministry of Health (MOH) with approval number 21-57E.

Results

Teleradiology survey

The teleradiology survey included responses from 82 individuals professionally involved in teleradiology. The survey statements are available in Supplementary Table 1.

Demographic information

Most respondents (78%) identified as male. In terms of location, 37.8% of the total respondents hailed from the northern border area, followed by 15.9% from the eastern region. Of the respondents, technologists accounted for 42.7% of the responses, whereas administrative staff constituted the smallest group, with only 3.7% of the responses. Some questions/statements exclusively targeted teleradiologists to gain insight into their payment methods. Of the nine respondents who provided input, most (8 respondents, 88.9%) reported being compensated on the basis of the number of cases they handled. The remaining respondents indicated receiving payments according to the number of hours worked. A subset of these items was intended solely for respondents with particular job descriptions. Respondents who did not meet these criteria were excluded from the results pool. The supplementary material (Supplementary Table 2) presents the groups considered in the final statistical examination.

The distribution of sex varied among job descriptions. The findings indicated that all respondents classified as administrative or referring physicians were male. The most significant proportion of female respondents, 34.3%, were identified within the technologist category, whereas 33.3% were female teleradiologists. The static package in R version 4.1.3 was employed to conduct the Fisher–Freeman–Halton test, which aimed to assess potential disparities in sex distribution among the various categories. This particular test is tailored to compare percentages among distinct and unrelated categories. Our analysis revealed statistically noteworthy variations in sex distribution across job categories ($p=0.022$). The sex distribution within each job description is presented in Fig. 1.

Overall responses

Remarkably, 96.2% of the respondents agreed with the idea that teleradiology services effectively address clinical questions (Q10), indicating a high level of consensus on the clinical utility of this approach. Another 90% of the participants indicated satisfaction with teleradiology services, indicating positive sentiment towards the quality and efficiency of the provided services. A substantial 93% of the respondents agreed on the importance of standardising MR imaging protocols across MOH hospitals, highlighting the collective recognition of the benefits associated with protocol consistency (Fig. 2). Among the respondents, 92.4% agreed with the advantageous nature of teleradiology and envisioned its capacity to serve as a transformative strategy for Saudi hospitals. In contrast, 96% of the respondents disagreed with the notion that teleradiology is disadvantageous. Item No. 4 (Q4) considered the ability to access patients' clinical data and garnered the next highest level of disagreement, with 77% of participants indicating dissent. Supplementary Table 3 offers a comprehensive presentation of the response distributions across all survey items. Further analysis revealed no statistically significant differences in agreement levels based on the participants' job descriptions (Supplementary Table 4).

No variance in agreement levels was observed among respondents according to their location, except for item 20 (Q20). In this regard, a distinction emerged between

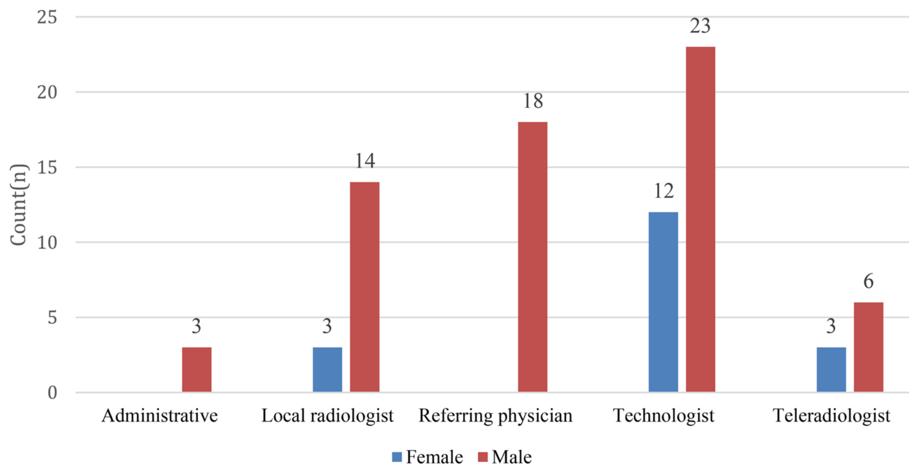

Fig. 1 Distribution of males and females across various job descriptions

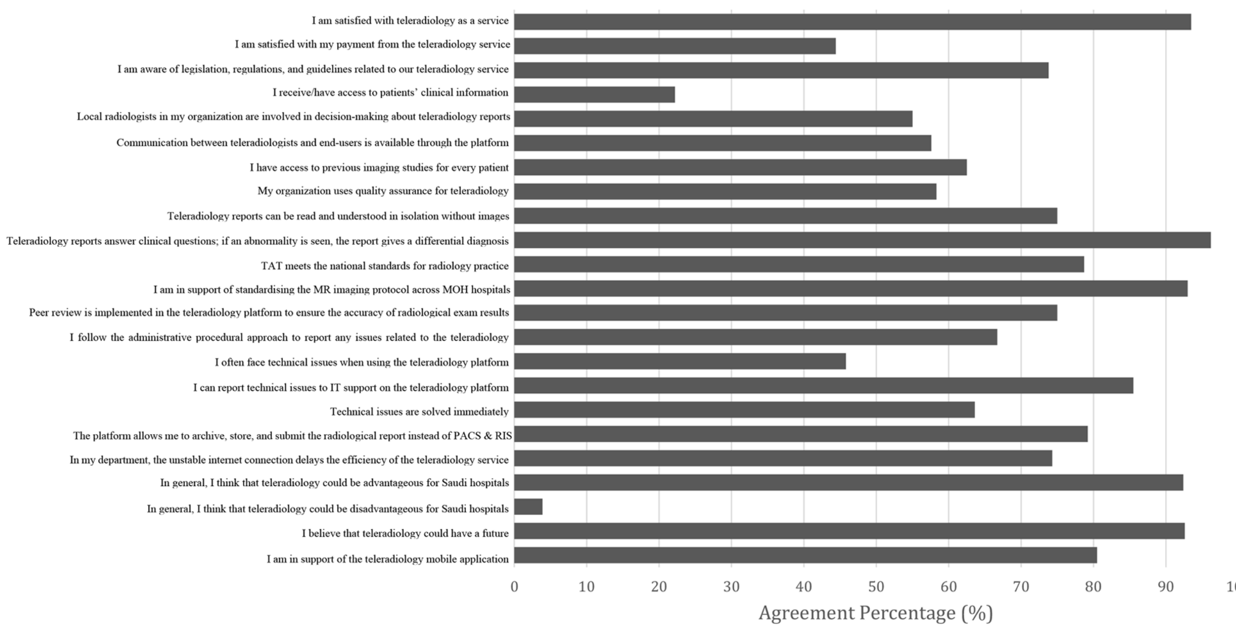

Fig. 2 Agreement percentages for teleradiology survey items. The turn-around time (TAT) aligns with national standards (CBAHI), with a duration of 48 h for routine cases, 24 h for urgent cases, and immediate reporting for emergency cases

Jazan (located in the southern region of Saudi Arabia), with 71.4% agreement, and the northern border, with 100% agreement, yielding a statistically significant difference ($p = 0.032$).

Advantages and disadvantages of Teleradiology

Among teleradiology respondents, there was a substantial endorsement of the specific benefits associated with teleradiology. These included enhancements in radiological reporting services (73.2%), notable efficiency gains in daily workflow (64.6%), the provision of second opinions (64.6%), and time savings in reporting (53.7%). Comparatively, the least frequently chosen advantage was facilitating case discussions in a collaborative network (25.6%), followed by effectiveness for educational purposes (28%), as depicted in Fig. 3. In contrast, the respondents' prevailing consensus on disadvantages involved inadequate communication with referring clinicians, with an agreement rate of 67.1%. Concerns about the security of the teleradiology platform had the lowest level of consensus, with only 3.7% of participants, whereas the majority reported confidence in the security of transmitted data through the same platform. The following statement, on which the respondents did not agree, pertained to the instability of teleradiology platform access (8.5%), as illustrated in Fig. 4.

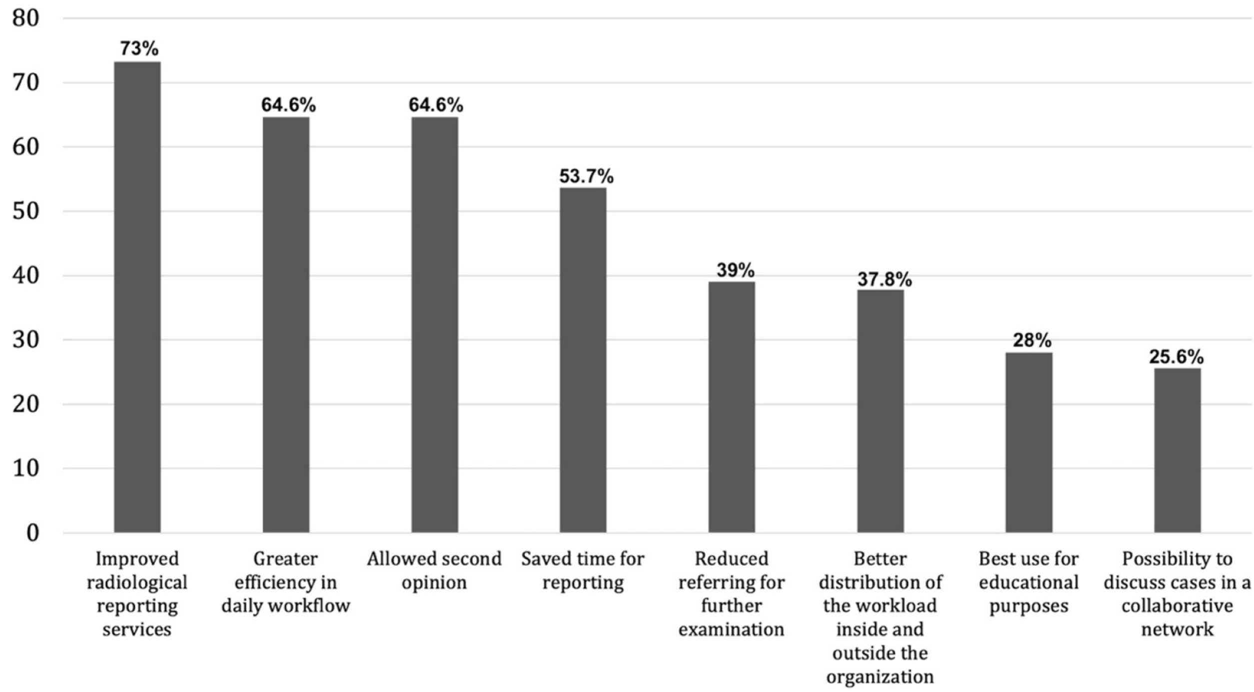

Fig. 3 Advantages of the teleradiology platform as indicated by respondents' preferences expressed as percentages (%)

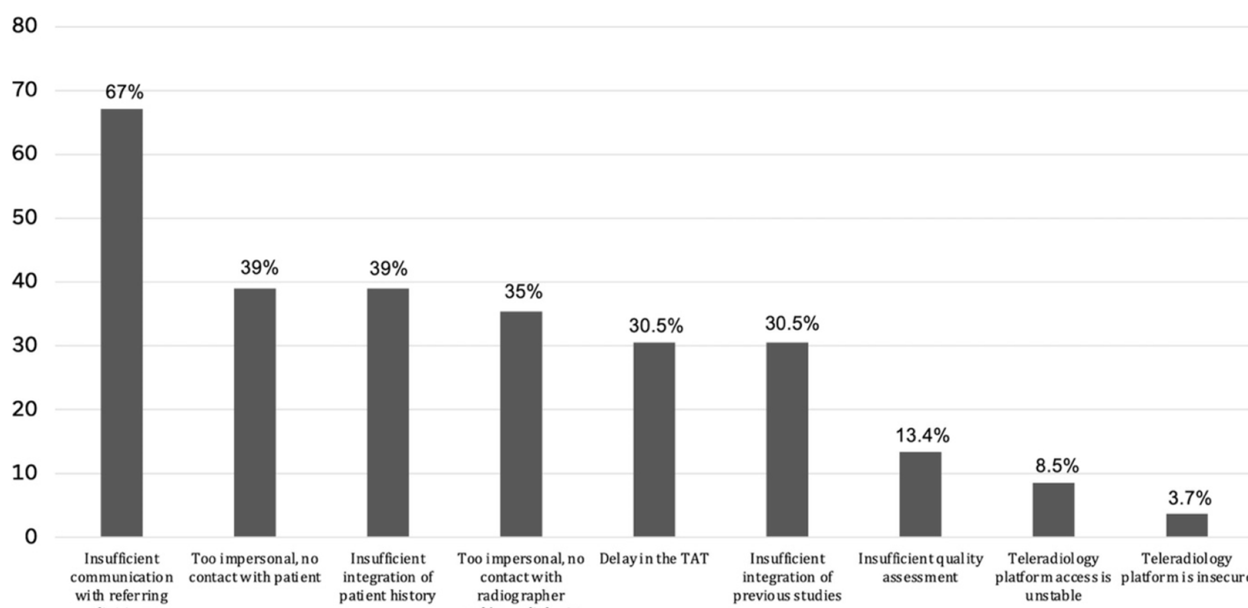

Fig. 4 Disadvantages of the teleradiology platform as indicated by respondents' preferences expressed as percentages (%)

Teleradiology report results for the brain and spine

Brain reports

In the RSNA structured report template, every structured brain report should comprise nine fundamental elements: clinical information, technique, IV contrast, comparison, brain parenchyma, ventricles/extra-axial spaces, flow voids, extracranial structures, and impressions. Reports encompassing a more extensive array of these elements are considered more robust because they adhere more faithfully to the prescribed structure. Of the reports examined, only two included all nine elements. The most elements within a single report were $n=45$ (44%) reports with seven elements, followed by $n=28$ (27%) reports with eight elements from the structured report template.

Table 1 Summary statistics of the number of elements included in the Brain reports

Elements (*n*)	Reports (*n*)	Percentage (%)
3	1	1.0
4	3	2.9
5	11	10.8
6	12	11.8
7	45	44.1
8	28	27.5
9	2	2.0
Mean number of elements		6.85
Minimum number of elements		3
Maximum number of elements		9

Table 2 Summary statistics of the number of elements included in the spine reports

Number of Elements Included	Number of Reports (*n*)	Percentage (%)
0	0	0.0
1	2	1.8
2	7	6.4
3	19	17.3
4	24	21.8
5	34	30.9
6	15	13.6
7	9	8.2
Mean number of elements		12.5
Minimum number of elements		0
Maximum number of elements		30.9

According to the information in Table 1, an average of approximately 6.85 elements were present in the 102 reports. Of the individual reports, the fewest elements observed in any single report was 3, whereas the maximum was 9.

Spine reports

A total of 110 MRI reports focused on the spinal region were obtained from the teleradiology platform. The comprehensive framework of the RSNA prescribes the inclusion of 12 distinct elements within each structured report: clinical information, technique, intravenous (IV) contrast, comparative analysis, exclusive enumeration for the lumbar (L) spine, spinal cord evaluation, terminal termination for the conus within the L spine, intervertebral disc analysis, osseous structure appraisal, soft tissue examination, central thoracic line (CTL) observations, and impressions. A significant proportion of the spine MRI reports (56.4%) included clinical information, but the low back pain reports included 2 to 7 of the required 12 elements. However, no reports included all 12 feasible elements. A modest subset, 11 reports (10%), integrated 11 of the 12 elements. The arithmetic mean, computed across the spectrum of 110 spinal MR reports, revealed the inclusion of 8 elements. Thus, the average report included 8.33 of the 12 prescribed constituents within the structured report template (Table 2).

Table 3 Number of reports grouped by clinical impression

Clinical Impression	Frequency	%
Unremarkable, normal	58	56.9
Lesions	8	7.8
Vascular-related pathologies	25	24.5
Neurodegeneration	4	3.9
Other	6	5.9
Not mentioned	1	1.0

Table 4 Summary statistics of the number of 8 remaining elements included in the Brain MRI reports by impression

Impression	*N*	Mean	Minimum	Maximum
Normal	58	5.81	3	8
Abnormal	43	6.00	3	8

Reports by impression

Brain reports

The data analysis involved categorising the reports according to their clinical impressions. Our hypothesis suggested a potential correlation between clinical impressions and the amount of information contained in these reports. We classified clinical impressions into five categories: (a) normal/unremarkable, (b) lesions, (c) vascular-related pathologies, (d) neurodegeneration, and (e) other, including various pathological cases. One report that lacked a clinical impression was excluded from this analysis. The results revealed that patients with normal clinical impressions were predominant (n=58, 56.9%), followed by patients with vascular-related pathologies (n=25, 24.5%). The additional categories are displayed in Table 3.

Abnormality-based group analysis

For a more extensive analysis of these reports, we aggregated all the reports featuring pathologies and labelled them "abnormal." Within this analysis, 58 reports were classified as normal, and 43 were classified as abnormal; one report that lacked an impression was excluded. Of the 58 reports with a normal impression, only one report (1.7% of the 58) included all eight additional elements. Of the 43 reports with an abnormal impression, only one (2.3% of the 43) contained all eight additional elements.

Despite the limited occurrence of reports featuring all eight additional elements, Fisher's exact test was conducted to assess the percentage comparison. The findings did not indicate a noteworthy contrast in the proportion of reports containing all other elements between the normal and abnormal categories. As detailed in Table 4, the mean count of elements incorporated in the normal reports was 5.81, slightly lower than the mean count in the abnormal reports, which was 6. A comparison of the normal and abnormal reports via the Mann‒Whitney U test yielded a result of z = -0.802, $p=0.423$, indicating a lack of statistically significant variance in the number of elements included within the reports.

Spine reports

We categorised the spine MRI reports according to their clinical impressions. This particular element was further divided into four subcategories: (a) normal and unremarkable, (b) vertebrae-related pathologies and degeneration, (c) disc-related diseases, including disc bulge and spondylolysis, and (d) unspecified. Of the 110 reports, 20 (18.2%) indicated a normal and unremarkable clinical impression, whereas the most prevalent impression was disc disease, disc bulge, or spondylolysis, accounting for 81 reports (73.6%). For this analysis, we consolidated all reports with pathological findings (excluding normal cases) under the label "abnormal" (Table 5).

This analysis yielded two distinct groups:

1. Reports classified as normal (n = 20), and
2. Reports classified as abnormal (n = 86).

The four reports lacking any clinical impression were excluded from this supplementary analysis.

Our objective was to ascertain whether a disparity existed in the number of additional elements included in the reports (excluding the clinical impression) when contrasting the normal and abnormal reports. Although none of the reports featured all 11 elements, the mean number of elements incorporated in the normal reports was 6.50, indicating a lower average than in the abnormal reports, which averaged 7.58 elements.

Abnormality-based group analysis

To investigate whether this difference in the typical number of elements between the normal and abnormal reports was statistically significant, we conducted a non-parametric Mann‒Whitney U test. Our analysis revealed a statistically significant distinction (z = -2.657, $p=0.008$) in the number of elements included within the reports featuring normal and abnormal impressions. Notably, the abnormal reports included more of these elements (Table 6).

Table 5 Number of spine MRI reports with each clinical impression

Clinical Impression	Frequency	Percentage
Normal, unremarkable	20	18.2
Vertebrate-related pathologies, degeneration	5	4.5
Disc disease, disc bulge, spondylosis	81	73.6
Not mentioned	4	3.6

Table 6 Summary statistics of the 11 remaining elements included in the spine MRI reports by impression

Impression	*N*	Mean	Minimum	Maximum
Normal	20	6.50	4	10
Abnormal	86	7.58	4	10

Table 7 Number of reports grouped by clinical information

Clinical Information	Frequency	Percent
Nonstructural pathology	42	41.2
Lesions, CVA, tumours, MS, dementia, ageing, FTD, Alzheimer's disease	17	16.7
Seizures	8	7.8
Small regions	11	10.8
Not mentioned	19	18.6
Others	5	4.9

Reports by clinical information

Brain reports

Our objective was to further examine the data according to the clinical information element and its potential influence on determining the extent of content included in the reports. Therefore, the reports were categorised into five groups: (a) nonstructural pathology; (b) neurodegenerative disease and lesions (such as cerebral vascular accident (CVA)/tumours/MS/dementia/ageing/FTD/Alzheimer's disease, consolidated owing to the limited number of reports); (c) seizures (e.g., epilepsy); (d) small region cases, such as orbits, IAM, and pituitary; and (e) others, including dural pathologies.

Table 7 displays a breakdown of the reports ($n=42$, 41.2%) featuring nonstructural pathology within the clinical information section. The subsequent category of reports ($n=17$, 16.7%) included lesions, CVA, and neurodegenerative diseases as the primary types of clinical information. The table presents the remaining categories, highlighting comprehensive clinical information for most nonstructural pathology cases. To further explore potential distinctions, we aggregated all pathological cases into a single group named "structural pathology." This involved identifying group A as nonstructural pathology reports ($n=42$) and group B as structural pathology reports ($n=41$). The aim was to investigate whether the inclusion of other elements in the reports in addition to clinical information differed when contrasting the nonstructural and structural pathology reports. Table 7 shows how the 102 reports were divided among the different types of clinical information.

We omitted reports that lacked clinical information ($n=19$). None of the nonstructural pathological reports ($n=42$) included all 8 additional elements. Conversely, among the structural pathology reports, only a limited number ($n=2$, 4.9%) contained all 8 additional elements. No significant distinctions were observed ($p<0.241$) in the percentage of reports that contained all other elements between patients with structural and nonstructural pathologies. As depicted in Table 8, the mean number of elements in the nonstructural pathology reports was 5.81 (minimum=4, maximum=7), which was slightly lower than the 6.29 (minimum=4, maximum=8) reported in the structural pathology reports.

To assess whether the quantity of elements differed significantly between reports featuring structural and nonstructural pathology information, a nonparametric test was conducted. The outcome revealed a statistically significant distinction (z = -2.177, p=0.030), indicating that the number of included elements varied between these two types of reports. Reports with structural pathology information generally include a greater number of elements.

Table 8 Summary statistics of the number of 8 elements included in the reports grouped by clinical information

Clinical Information	*N*	Mean	Minimum	Maximum
Nonstructural pathology	42	5.81	4	7
Structural pathology	41	6.29	4	8

Spine reports

We categorised the reports according to their clinical information (Table 9). This element was further segmented into three categories: (a) lower back pain, (b) neck pain, and (c) other. Of the 110 included reports, most were lower back pain reports (n=62, 56.4%). The "other" subcategory accounted for the next highest portion (n=35, 31.8%), while fewer reports were attributed to neck pain (n=9, 8.2%).

Four reports that lacked clinical information were omitted from this analysis. On average, the "lower back pain" reports represented 7.77 of the 11 elements, whereas the "neck pain" reports averaged 7.56 of the 11 elements. In contrast, the "other" reports had the lowest average, 6.66, of all other categories. The minimum and maximum number of elements for each category are shown in Table 10.

We conducted a nonparametric analysis employing the Kruskal–Wallis test to compare multiple groups. This test aimed to examine whether the typical number of elements reported across various groupings of reports exhibited significant differences. Our objective was to statistically evaluate whether the number of elements reported on the basis of clinical information differed meaningfully among these groups.

Our analysis revealed a significant disparity ($\chi^2(2)$=9.591, p=0.008) in the number of included elements among reports associated with different clinical information. To identify the group with the highest reported element count, we conducted individual Mann–Whitney tests. These tests indicated that the number of elements tended to be greater for the "lower back pain" reports (z=3.064, p=0.007) than for those categorised as "other" spine-related cases.

Table 9 Number of reports grouped by clinical information

Clinical Information	Frequency	Percentage
Lower back pain	62	56.4
Neck pain	9	8.2
Other	35	31.8
Not mentioned	4	3.6

Table 10 Summary statistics of the number of 8 elements included in the reports grouped by clinical information

Clinical Information	*N*	Mean	Minimum	Maximum
Lower back pain	62	7.77	4	10
Neck pain	9	7.56	4	9
Other	35	6.66	3	10

Table 11 Summary statistics of the number of elements included in the MRI reports grouped by years of experience of the teleradiologists

	Years of Experience	No. of Tele radiologists	Mean No. of Elements Included	Minimum	Maximum
Brain	Less than 20 years	8	7.12	5.83	8.50
	More than 20 years	2	6.79	6.50	7.09
Spine	Less than 20 years	12	7.91	6.00	10.25
	More than 20 years	2	8.91	8.76	9.05

Radiologists' years of experience

The radiologists with less than 20 years of experience included an average of 7.12 elements of 9 in the brain reports and 7.91 elements of 12 in the spine reports (Table 11). The radiologists with more than 20 years of experience had a slightly lower average score of 6.79 of 9 elements in the brain reports and a higher average score of 8.91 of 12 elements in the spine reports.

Despite the limited number of teleradiologists with more than 20 years of experience (n=2), the statistical power of the independent (two-sample) t test was somewhat constrained. Nevertheless, we attempted to assess any noteworthy differences in years of experience among radiologists. Our analysis indicated that for brain reports, the comparison between radiologists did not yield a statistically significant outcome (t [8]=0.448, p=0.666). However, for spine reports, notable differences were observed (t [12] = -1.058, p=0.155) in terms of years of experience among radiologists.

Discussion

These outcomes collectively highlight the widespread alignment of the participants' opinions concerning the effectiveness, satisfaction, standardization, and potential benefits of teleradiology services within Saudi hospitals. The high percentages of agreement observed in these results reflect a robust consensus on key aspects of teleradiology's value and prospects.

During the pandemic, many remote hospitals in Saudi Arabia embraced teleradiology services [13]. These remotely provided services helped minimise the physical engagement of radiologists with patients on a global level [14, 15]. Although teleradiology is the most widely known application of telemedicine, concerns have been raised about how it will change medical imaging practices. Local radiologist respondents in remote areas of Saudi Arabia expressed concerns about potential risks to their reputation and professional standing as local radiologists due to implementing teleradiology [16]. Nevertheless, most responses concur that teleradiology is advantageous, with many supporting its benefits and acknowledging its promising future [6]. Notably, there was a striking sex disparity in the responses, with males constituting 78% of the participants and females representing only 22%. This disparity reflects the relatively low number of women actively engaged in the field of medical imaging [17, 18]. These sex differences and male predominance are also evident in other medical subspecialties [19, 20]. Women bring a different perspective to the workplace. Thus, we can use these findings to highlight issues related to sex imbalances in radiology and encourage solutions such as proper education about careers in radiology [21], early mentorship, part-time opportunities [22], and ways to eliminate biases in program acceptance and promotions [23]. Teleradiology may be more convenient for women than other medical specialties because of the flexibility in working hours and methods of reporting [24]. Among all the respondents, most were technologists due to the nature of engagement in teleradiology from multiple remote hospitals compared with the limited number of teleradiologists who were actively engaged in the teleporting of radiological examinations. There was no notable variation in the level of agreement on all statements among the respondents on the basis of sex, job description, or the location of responses. Of these responses, standardising imaging protocols was identified as a crucial area for development. Standardization plays a pivotal role in ensuring appropriate and effective outcomes, particularly in medical imaging. It encompasses various elements, including policies, procedures, and workflows, which collectively contribute to achieving consistency and optimal results. Teleradiologists in Saudi Arabia are employed full-time at prominent hospitals in urban areas and offer teleradiology services after hours. These teleradiologists possess diverse imaging experiences and face challenges when reporting critical cases without appropriate imaging protocols. In response to these challenges, two potential solutions can be proposed. The first is implementing standardised imaging protocols across remote sites affiliated with the main institution, the MOH, which could yield significant benefits [25]. Second, licensure programs for teleradiologists with a focus on equipping them with the essential skills to report on diverse imaging protocols might also offer a viable remedy [26]. MR examinations and imaging protocols are notoriously different from site to site. We recognise that standardising protocols poses a significant challenge; however, it is not an insurmountable task [27, 28]. It requires an iterative process, dedicated personnel, and collaborative efforts for continuous development. A proposed model for strategic personalization and standardization was previously published that included a collaborative team of MR physicists, radiologists, and clinicians to optimise protocols on the basis of clinical needs [29]. The other important element is system stability and continuous IT support for technical errors. Image transmission, downloading and viewing, links to reports, the speed of connection, and the uploading of correct documentation are demands that are technically easy for teleradiology system providers to fulfil. Most respondents (85.5%) believed that IT support was achieved through the teleradiology platform and that it was secure (96%). However, most of the respondents complained about an unstable platform, which opens doors for future research.

Teleradiology reports are rarely standardised in a structured reporting style. The reports are heterogeneous and nonuniform, which presents a great challenge in evaluating the quality and comparability of reports. Online access to radiology reports enables teleradiology service providers to adopt a systematic reporting approach. This is facilitated by using subheadings and convenient dropdown list options for efficient and organised reporting [12]. This is important for consistency, faster information extraction, and reducing the number of missing key elements [30]. The literature has previously supported the development of mobile/tablet applications [31], an idea that garnered support from more than 80% of the respondents. By enabling notifications for each newly uploaded or urgent case on the platform, reporting can be expedited, and the turnaround time (TAT) can be significantly reduced. Another useful function of mobile teleradiology applications is to facilitate communication between medical team members, which is an issue noted by many respondents (67%). There are many forms of communication: (a) live consultation with a teleradiologist for contrast injections [32], (b) remote access by clinicians to view reports [33], and (c) consultation between the ER team and specialists before decision-making regarding clinical management [34, 35]. Because communication remains a persistent challenge in teleradiology, incorporating interactive features such as live chats, groups, and broadcast lists in a mobile app can greatly enhance the user experience. This approach enables all users, regardless of location, to actively participate in the workflow of each site, effectively allowing them to operate "locally." By fostering seamless collaboration, this system significantly boosts productivity for radiology practice. Artificial intelligence (AI) represents a cutting-edge trend in medical imaging, and its implementation is made more accessible through seamless IT integration within teleradiology platforms and mobile apps. Collaborative discussions about critical cases in imaging departments were found to change 50% of diagnoses and 60% of treatment plans [36] and improve the understanding of pathology [37]. However, this is restricted by teleradiology, as indicated by the responses of our participants. International guidelines suggest conducting virtual multidisciplinary meetings to maximise the understanding of the clinical problems of radiologists [38].

Another significant challenge is the inaccessibility of previous radiological examinations or the patient's clinical history, which are essential for any radiology practice [38]. Consolidating accessible resources for patient data across all remote sites is a logical step for teleradiology providers. The Saudi MOH is currently working on the Unified Health File (UHF) project, a digital health platform that provides updated patient data and is accessible through all MOH sites [39]. Securing access to teleradiology platforms can effectively overcome the major challenges teleradiologists face.

Research has revealed that a 15-minute reporting delay significantly diminishes the likelihood of favourable outcomes in urgent cases such as strokes [40]. Although this issue was raised, it did not receive support from most respondents (70%), in alignment with previous studies, particularly for urgent cases [41]. We found that the teleradiology services implemented in Saudi Arabia provide a TAT of 15 min to 6 h, which is within the range set by the national standard of the CBAHI. The smartphone client–server teleradiology system shows promise and the potential to facilitate urgent management decisions in critical cases [40]. Teleradiology allows second opinions to be provided promptly [42], which was highlighted during the pandemic [13, 43]. The current study shows that a second opinion is an added value service for remote hospitals. It improves the daily workflow and reduces pressure on remote hospitals with few experts. As a long-term option, external teleradiology partnerships are appealing since no interviews or contract hires are required, and the need for extra staffing based on imaging volume is reduced.

Well-established, frequent clinic-radiological meetings to discuss discrepancies and errors maintain the quality of diagnosis for challenging cases such as cancer management. While this is restricted in teleradiology, teleconferencing and IT integration can enable medical teams to have virtual meetings through the teleradiology platform. National health regulatory authorities should establish teleradiology policies and standards in alignment with international guidelines. Annual quality evaluation of teleradiology, including system quality assurance, quality control reporting, and revalidation requirements for teleradiologists, should be regulated in teleradiology guidelines. Within radiology, evaluating image reporting through peer review involves evaluating the precision of a report issued by a different radiologist. These findings hold promise for meeting the escalating quality enhancement demands of regulatory bodies. Nonetheless, peer review still faces challenges and awaits broader endorsement.

This study aimed to examine the application of structured formats in teleradiology reports within the Saudi context and determine whether these reports follow any structured format or adhere to recognised standards. The RSNA templates were selected because of their wide acceptance and usage in the radiology community. By evaluating the reports against the RSNA templates, the goal was to assess the extent of structured reporting utilization and identify potential areas for enhancement. The quality assessment of teleradiology reports from both brain and spine MRI examinations was selected because these are the most common modalities for teleradiology use in remote regions in Saudi Arabia. Although teleradiologists had over 10 years of experience, none of the reports followed a structured format. When the reports were compared with the RSNA template, of all the brain MRI reports, only two included all 9 elements from the structured RSNA template, whereas none of the spine reports included all 12 elements from the RSNA template. A previous study revealed substantial 10-fold variability in radiologists' reporting styles across many datasets when both natural language processing and machine learning models were employed [44, 45]. Furthermore, it has been reported that different radiologists who interpret the same MRI examination show high variability in their findings when they do not follow a reporting template [46]. The number of elements did not differ between reports of normal or pathological findings in brain MRI. In contrast, pathological spine MRI reports included a greater number of elements. When spine MRI images with conventional reports were reviewed via a structured approach, missing extraspinal findings were significant [47]. This finding is particularly alarming, especially for subspecialist radiologists, who may not be familiar with interpreting abdominal/pelvic

MRI scans. The implications underscore the importance of employing structured approaches in radiology reporting to avoid overlooking critical information, especially for those dealing with unfamiliar imaging domains. As highlighted in previous studies, patients' healthcare management, outcomes, and therapeutic options depend on the quality of radiologists' reports [48, 49]. Intriguingly, studies have identified a notable pattern: when clinical information suggests the need to rule out pathologies, reports tend to incorporate more elements from the structured report than cases with nonpathological clinical information. This finding suggests that including specific clinical information may influence the level of detail and comprehensiveness of structured reports. A previous study examined the reporting practices of Saudi academic hospitals and reported that radiologists often do not follow any systematic approach when generating their reports [50]. The reports were highly heterogeneous, with significant variability and frequent omissions of critical information. On the basis of these findings, it was hypothesised that teleradiology, as a national initiative, would lead to a standardised reporting system. The current study aimed to investigate the implementation of structured reports within the teleradiology framework and assess their impact on report completeness. However, this was not the case, as the telereports did not follow a structured format, similar to the findings in academic hospitals [50]. While a direct comparison with nonteleradiology reports could further illuminate these differences, the findings from previous research underscore the potential benefits of structured reporting, particularly in enhancing the quality and completeness of radiology reports. Structured reporting has achieved global acceptance and is significantly transforming the landscape of radiological practice. This approach has the potential to enhance efficiency, accuracy, and communication in the field of radiology, benefitting both healthcare professionals and patients.

The development of disease-specific structured templates or macros is reflective of evidence-based society recommendations. National and international guidelines have contributed to the growth and spread of SRs in radiology practice. However, despite their global acceptance, structured reports have not yet gained popularity in the Middle East and North Africa (MENA) region. In healthcare, remote hospitals confront many obstacles that set them apart from their larger urban counterparts. To circumvent the need to refer challenging cases to major hospitals and facilitate faster decision-making at local hospitals, it is imperative to establish standardised imaging protocols and teleradiology reports when teleradiology services are adopted. By adhering to these standardised practices, healthcare providers can assess and maintain the quality of radiology services effectively, promoting seamless communication and enhancing patient care. Ongoing concerns regarding the accuracy of the reports issued by radiologists via teleradiology have been reported [13] and may be attributed to two main factors: first, the evident challenges in accessing patients' previous imaging studies or clinical data can impact the quality of interpretations; second, the lack of consistency in the report structure increases the potential for discrepancies in reports.

An additional drawback of the present service is its limited use for educational purposes and the training of fellowship programs. Currently, educational sessions are organised sporadically by enthusiastic volunteer teleradiologists contingent upon the availability of interesting medical cases. If formal legislation were to be implemented in collaboration with the Saudi Commission for Health Specialties, it would lead to an expansion of training and development opportunities for the radiology workforce.

Limitations

The response rate in this study was lower than anticipated, primarily because of the relatively few teleradiology users in Saudi Arabia. Importantly, the adoption of teleradiology in Saudi Arabia falls significantly below initial expectations [51]. Its implementation began only in 2018, which accounts for the relatively small pool of potential participants at the time of data collection. Unlike previous studies, the current research employed a well-established structured report to assess the quality of reports, effectively eliminating any variability associated with subjective grading systems. Furthermore, this study did not examine the additional hours teleradiologists work in addition to their full-time positions or how this affects the quality of their reports.

Recommendations

We foresee a powerful future of this technology in which teleradiologists play a vital role in remote image interpretation while adhering to licensing, certification, and quality standards. Teleradiology requires suitable work conditions and adherence to privacy rules. Furthermore, teleradiologists should engage in a range of activities, from image selection to resulting communication, to ensure patients' rights to privacy and clinical management. Collaboration with radiology technologists is crucial for quality control and patient information exchange, and turnaround times must align with hospital policies. Standardising imaging protocols, ensuring system stability, and addressing communication barriers are critical challenges (Table 12). The current literature does not suggest a direct correlation between teleradiology use and reporting completeness, as the quality and completeness of radiology reports are more closely related

Table 12 Teleradiology solutions and recommendations

Technical Factors	Human Factors	Legal and Regulatory Factors	Financial Factors	Quality
Invest in infrastructure to support teleradiology, including high-speed internet connectivity, secure data storage, and advanced image interpretation software.	Establish clear and effective communication protocols among radiologists, referring physicians, and other healthcare providers.	Lack of a standardised reporting style in teleradiology reports, resulting in heterogeneity.	Collaborate with stakeholders to iterate and refine teleradiology practices based on evolving technological advancements and healthcare needs.	Implement a rigorous annual quality assurance and quality control program that monitors the accuracy and reliability of images and interpretations.
Need for continuous IT support and system stability to ensure reliable and efficient teleradiology services.	Develop a system for handling urgent cases.	Ensure that all images and patient information are secure and comply with HIPAA regulations.		Perform regular audits, monitoring of key performance indicators, and ongoing training and education for radiologists.
Persistent challenges in communication among medical team members, including live consultations, remote accessibility to previous reports, and specialist consultations for clinical management.	Encourage collaboration and consultation among radiologists and other healthcare providers to ensure that patients receive the best possible care.	Establish standardised imaging protocols across remote sites affiliated with the main institution (Ministry of Health) to ensure consistent and optimal imaging outcomes.		Conduct further research on the challenges and benefits of teleradiology to address gaps in practice and improve the quality of services.
Integrate artificial intelligence (AI) capabilities into teleradiology platforms and mobile apps to enhance diagnostic accuracy, efficiency, and workflow.	Provide opportunities for professional development and knowledge sharing.	Address sex imbalances and promote inclusivity through education, mentorship, and opportunities for women in radiology.		
Develop a mobile/tablet application for teleradiology that enables notifications for urgent cases, expediting reporting and reducing the turnaround time (TAT).	Facilitate virtual multidisciplinary meetings through teleconferencing and IT integration to discuss critical cases and enhance collaborative decision-making.	If the Saudi Ministry of Health implements the Unified Health File (UHF), which provides updated patient data accessible through all MOH sites, this will address the issue of inaccessible previous clinical data.		
Incorporate interactive features into smartphone apps, such as live chats, groups, and broadcast lists to facilitate communication between medical team members and enhance user experience.		Establish teleradiology policies and standards in alignment with international guidelines through national health regulatory authorities.		
		Offer licensure programs for teleradiologists to ensure proficiency in diverse imaging protocols and enhance reporting skills.		

to the reporting style rather than the technology itself. The effectiveness of tele-radiology in enhancing report completeness largely depends on the implementation of systematic and standardised reporting practices and adherence to standardised protocols rather than the mere adoption of tele-radiology as a technology.

Conclusion

The COVID-19 pandemic has brought many challenges to the field of medical imaging. This study highlights the need for standardised practices, improved communication, and enhanced IT support to ensure efficient and high-quality teleradiology services. Teleradiology, though beneficial, raises concerns about potential challenges. A mobile app that enables notifications and communication could expedite reporting and enhance the user experience. Despite the potential benefits of structured reporting, its adoption in the region is slow. The cost-effectiveness of teleradiology is unparalleled compared with the expenditures related to specialised healthcare facilities. In addition to cost savings, teleradiology offers significant enhancements to various medical imaging services, including improved accessibility, faster turnaround times, and the ability to reach remote or underserved areas with quality diagnostic interpretations.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12913-024-11706-5.

Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Supplementary Material 4.

Acknowledgements

The authors extend their appreciation to The Central Research Laboratory/Research Institute/ Center Supporting Program (RICSP-24-3), King Saud University, Riyadh, Saudi Arabia.

Authors' contributions

AR; Supervision, Conceptualization, Methodology, Writing- Original draft preparation, Reviewing and Editing, AA; Investigation, Writing- and Original draft preparation FM; Investigation and Data Curation, HSA; Data Curation, SA; Data Curation. All authors reviewed the content and approved it.

Funding

This project was funded by the Central Research Laboratory/Research Institute/Center Supporting Program (RICSP-24-3), King Saud University, Riyadh, Saudi Arabia.

Availability of data and materials

All data used in this study available from the correspondence author upon request.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and received approval from the Central Institutional Review Board (IRB) of the Ministry of Health (MOH), under approval number 21-57E. Prior to starting the online questionnaire, the participants provided their informed consent electronically. This process was reviewed and approved by the Ethics Committee.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Radiological Sciences Department, King Saud University, Office 60, Building 11, Female Campus, Riyadh 11451, Saudi Arabia
[2]Scientists Unit, Central Research Laboratory, King Saud University, Riyadh 11495, Saudi Arabia
[3]Head of Radiology, Rafha Central Hospital, Ministry of Health, Rafha, Saudi Arabia
[4]Public Health Deputyship in the Ministry of Health, Riyadh, Saudi Arabia
[5]Department of Biochemistry, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia

Received: 30 May 2024 / Accepted: 3 October 2024
Published online: 31 October 2024

References

1. Coppola F, Bibbolino C, Grassi R, Pierotti L, Silverio R, Lassandro F, Neri E, Regge D. Results of an Italian survey on teleradiology. Radiol Med. 2016;121(8):652–9.
2. Shem S, Ugwu A, Hamidu A, Flavious N, Ibrahim M, Zira D. Challenges, opportunities and strategies of global health radiology in low and middle-income countries (LMICs): an excerpt review. J Cancer Prev Curr Res. 2022;13(1):14–20.
3. Burute N, Jankharia B. Teleradiology: the Indian perspective. Indian J Radiol Imaging. 2009;19(01):16–8.
4. Teleradiology and technology innovations in radiology: status in India and its role in increasing access to primary health care. The Lancet Regional Health - Southeast Asia 2024, 23.
5. Maher A, Bahadori M, Davarpanah M, Ravangard R. Factors affecting the establishment of teleradiology services: a case study of Iran. Shiraz E Med J. 2019;20(1):e69184.
6. Rosenkrantz AB, Hanna TN, Steenburg SD, Tarrant MJ, Pyatt RS, Friedberg EB. The current state of Teleradiology across the United States: A National Survey of radiologists' habits, attitudes, and perceptions on Teleradiology Practice. J Am Coll Radiol. 2019;16(12):1677–87.
7. Dixon AK, FitzGerald R. Outsourcing and teleradiology: potential benefits, risks and solutions from a UK/European Perspective. J Am Coll Radiol. 2008;5(1):12–8.
8. Ashcroft RE, Goddard PR. Ethical issues in teleradiology. Br J Radiol. 2000;73(870):578–82.
9. Jacobs JJWM, Ekkelboom R, Jacobs JPAM, van der Molen T, Sanderman R. Patient satisfaction with a teleradiology service in general practice. BMC Fam Pract. 2016;17(1):17.
10. European Society of R. ESR teleradiology survey: results. Insights into Imaging. 2016;7(4):463–79.
11. Saliba V, Legido-Quigley H, Hallik R, Aaviksoo A, Car J, McKee M. Telemedicine across borders: a systematic review of factors that hinder or support implementation. Int J Med Informatics. 2012;81(12):793–809.
12. RadReport. Template library [https://radreport.org].
13. Al-Dahery ST, Alsharif WM, Alamri FH, Nawawi SA, Mofti WK, Alhazmi FH, Alshamrani KM, Suliman AG, Qurashi AA. The role of teleradiology during COVID-19 outbreak: Saudi radiologists' perspectives. Saudi Med J. 2023;44(2):202.
14. Ain HQU, Tahir MJ, Waheed S, Ahmad S, Ullah I, Yousaf Z. Teleradiology in COVID-19: a sustainable innovative solution. Acad Radiol. 2021;28(9):1325–6.
15. Boufarasse YB, Ettahir A, Bekkali D, Bennani J. Teleradiology and AI as solution to overcome the COVID-19 pandemic impact during the lockdowns in Africa. Health Sci J. 2020;14(7):1–2.
16. Thrall JH. Teleradiology Part II. Limitations, risks, and opportunities. Radiology. 2007;244(2):325–8.
17. Qamar SR, Khurshid K, Jalal S, McInnes MDF, Probyn L, Finlay K, Hague CJ, Hibbert RM, Joshi M, Rybicki FJ, et al. Gender Disparity among Leaders of Canadian Academic Radiology Departments. Am J Roentgenol. 2019;214(1):3–9.
18. Zener R, Lee SY, Visscher KL, Ricketts M, Speer S, Wiseman D. Women in Radiology: exploring the gender disparity. J Am Coll Radiol. 2016;13(3):344–e350341.
19. Ahmadi M, Khurshid K, Sanelli PC, Jalal S, Chahal T, Norbash A, Nicolaou S, Castillo M, Khosa F. Influences for gender disparity in academic neuroradiology. Am J Neuroradiol. 2018;39(1):18.
20. Agrawal P, Madsen TE, Lall M, Zeidan A. Gender disparities in academic Emergency Medicine: strategies for the recruitment, Retention, and Promotion of women. AEM Educ Train. 2020;4(S1):S67–74.
21. Roubidoux MA, Packer MM, Applegate KE, Aben G. Female Medical Students' interest in Radiology Careers. J Am Coll Radiol. 2009;6(4):246–53.
22. Weigel KS, Kubik-Huch RA, Gebhard C. Women in radiology: why is the pipeline still leaking and how can we plug it? Acta Radiol. 2020;61(6):743–8.
23. Spalluto LB, Arleo EK, Lewis MC, Oates ME, Macura KJ. Addressing needs of women radiologists: opportunities for Practice leaders to facilitate change. Radiographics. 2018;38(6):1626–37.

24. Goelz L, Arndt H, Hausmann J, Madeja C, Mutze S. Obstacles and solutions driving the development of a National Teleradiology Network. Healthcare. 2021;9(12):1684.
25. Kaufmann TJ, Smits M, Boxerman J, Huang R, Barboriak DP, Weller M, Chung C, Tsien C, Brown PD, Shankar L, et al. Consensus recommendations for a standardized brain tumor imaging protocol for clinical trials in brain metastases. Neurooncology. 2020;22(6):757–72.
26. Eberhardt SC, Heilbrun ME. Radiology Report Value Equation. RadioGraphics. 2018;38(6):1888–96.
27. Sachs PB, Hunt K, Mansoubi F, Borgstede J. CT and MR Protocol standardization across a large Health System: providing a consistent radiologist, patient, and referring provider experience. J Digit Imaging. 2017;30(1):11–6.
28. Glazer DI, DiPiro PJ, Shinagare AB, Huang RY, Wang A, Boland GW, Khorasani R. CT and MRI protocol variation and optimization at an Academic Medical Center. J Am Coll Radiol. 2018;15(9):1254–8.
29. Sharma PS, Saindane AM. Standardizing magnetic resonance imaging protocols across a large Radiology Enterprise: barriers and solutions. Curr Probl Diagn Radiol. 2020;49(5):312–6.
30. Carter SM, Rogers W, Win KT, Frazer H, Richards B, Houssami N. The ethical, legal and social implications of using artificial intelligence systems in breast cancer care. Breast. 2020;49:25–32.
31. Engelmann U, Schröter A, Borälv E, Schweitzer T, Meinzer H-P. Mobile teleradiology: all images everywhere. Int Congr Ser. 2001;1230:844–50.
32. Drnasin I, Gogic G, Tonkovic S. Interactive teleradiology. World Congress on Medical Physics and Biomedical Engineering, September 7–12, 2009, Munich, Germany: 2009// 2009; Berlin. Heidelberg: Springer Berlin Heidelberg; 2009. pp. 290–4.
33. Tahir MY, Mars M, Scott RE. A review of teleradiology in Africa–towards mobile teleradiology in Nigeria. SA J Radiol. 2022;26(1):2257.
34. Demaerschalk BM, Vargas JE, Channer DD, Noble BN, Kiernan T-EJ, Gleason EA, Vargas BB, Ingall TJ, Aguilar MI, Dodick DW, et al. Smartphone Teleradiology Application is successfully Incorporated into a Telestroke Network Environment. Stroke. 2012;43(11):3098–101.
35. Kim DK, Kim EY, Yang KH, Lee CK, Yoo SK. A Mobile Tele-Radiology Imaging System with JPEG2000 for an Emergency Care. J Digit Imaging. 2011;24(4):709–18.
36. Dalla Palma L, Stacul F, Meduri S, Geitung JT. Relationships between radiologists and clinicians: results from three surveys. Clin Radiol. 2000;55(8):602–5.
37. Darras KE, Forster BB, Spouge R, de Bruin ABH, Arnold A, Nicolaou S, Hu J, Hatala R, van Merriënboer J. Virtual dissection with clinical radiology cases provides Educational Value to First Year Medical Students. Acad Radiol. 2020;27(11):1633–40.
38. ESR ESoR. ESR white paper on teleradiology: an update from the teleradiology subgroup. Insights into Imaging. 2014;5(1):1–8.
39. Unified Health File [https://www.moh.gov.sa/en/Ministry/Unified-Health-File/Pages/default.aspx].
40. Mitchell JR, Sharma P, Modi J, Simpson M, Thomas M, Hill MD, Goyal M. A smartphone client-server Teleradiology System for primary diagnosis of Acute Stroke. J Med Internet Res. 2011;13(2):e31.
41. Martinon A, Le Pogam MA, Boublay N, Ganne C, Ben Cheikh A, Buron C, Thomson V, Berthezène Y, Journé C. Teleradiology saves times in cases of vital emergencies: a comparative study with on-call radiology in two urban medium-sized French hospitals. Eur Res Telemedicine / La Recherche Européenne en Télémédecine. 2014;3(4):151–60.
42. Barneveld Binkhuysen FH, Ranschaert ER. Teleradiology: evolution and concepts. Eur J Radiol. 2011;78(2):205–9.
43. Rackimuthu S, Hasan MM, Ray I, Sahito AM, Chawla P, Ghosh D. Teleradiology in India during the COVID-19 pandemic: merits, pitfalls and future perspectives. Health Policy Plann. 2022;37(9):1203–6.
44. Donnelly LF, Grzeszczuk R, Guimaraes CV, Zhang W, Bisset Iii GS. Using a Natural Language Processing and Machine Learning Algorithm Program to Analyze Inter-radiologist Report Style Variation and compare variation between Radiologists when using highly structured Versus more free text reporting. Curr Probl Diagn Radiol. 2019;48(6):524–30.
45. Donnelly LF, Grzeszczuk R, Guimaraes CV. Use of Natural Language Processing (NLP) in evaluation of Radiology reports: an update on applications and technology advances. Seminars Ultrasound CT MRI. 2022;43(2):176–81.
46. Saha A, Grimm LJ, Harowicz M, Ghate SV, Kim C, Walsh R, Mazurowski MA. Interobserver variability in identification of breast tumors in MRI and its implications for prognostic biomarkers and radiogenomics. Med Phys. 2016;43(8):4558.
47. Quattrocchi CC, Giona A, Di Martino AC, Errante Y, Scarciolla L, Mallio CA, Denaro V, Zobel BB. Extra-spinal incidental findings at lumbar spine MRI in the general population: a large cohort study. Insights into Imaging. 2013;4(3):301–8.
48. Brady A, Laoide R, McCarthy P, McDermott R. Discrepancy and error in radiology: concepts, causes and consequences. Ulster Med J. 2012;81(1):3–9.
49. Karran EL, Medalian Y, Hillier SL, Moseley GL. The impact of choosing words carefully: an online investigation into imaging reporting strategies and best practice care for low back pain. PeerJ. 2017;5:e4151.
50. Alruwaili AR, Jamea AA, Alayed RN, Alebrah AY, Alshowaiman RY, Almugbel LA, Heikal AG, Alkhanbashi AS, Maflahi AA. A critical examination of Academic Hospital practices—paving the way for standardized structured reports in Neuroimaging. J Clin Med. 2024;13(15):4334.
51. Alshamrani K, Alkenawi A. Teleradiology public-private partnerships in Saudi Arabia: a review. Int J Med Developing Ctries. 2021;5:1096–9.

Publisher's Note