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Research Article

Artificial Intelligence in Urology: AI-Assisted Stone Detection, Prostate MRI Interpretation, and Operative Planning.

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Abstract: ***Background:*** Artificial Intelligence (AI) has become a promising tool in the field of urology where it has been used in diagnostic imaging, prostate cancer assessment and surgical planning. But there is limited evidence of its clinical practicality in tertiary care in Pakistan. ***Objective:*** To Assess the Clinical Utility and Diagnostic Performance of AI aiding in the Detection of Urinary Stones, Prostate MRI reading and Operating Planning at Ayub Teaching Hospital, Abbottabad. ***Methodology:*** An observational study was carried out at Ayub Teaching Hospital in which the hospital based approach was used. A total of 60 patients were assessed for urinary stones, 40 patients were being evaluated with prostate MRI and 20 patients were being evaluated for AI assisted operative planning. The results of AI were compared with the results of specialists, and, in cases of prostate cancer, the results of pathohistology served as the reference standard. Diagnostic performance, agreement, anatomical visualization, utility of the operative planning, and selected perioperative outcomes were evaluated. ***Results:*** AI-supported stone detection had an excellent agreement with specialist assessment (κ=0.87; p<0.001) and high sensitivity, specificity and accuracy (94.2%). AI had a high level of agreement with the specialist interpretation (κ=0.82, p<0.001) and a high level of accuracy (91.3%), sensitivity (90.0%) and specificity (92.5%) for prostate MRI. During operative planning, AI systems contributed to improving visualization of anatomy in 90.0% of cases, supporting procedure selection in 85.0% of cases, and enhancing the anticipation of operatives' complexity in 80.0% of cases. ***Conclusions:*** AI successfully performed well in several domains of urological practice and was found to have a high level of diagnostic performance and diagnostic utility. It proved to have its greatest benefit when used in conjunction with specialist expertise as an aid, rather than as a replacement, to clinical decision making.

Keywords: Artificial Intelligence, Diagnostic Imaging, Magnetic Resonance Imaging, Operative Planning, Prostate, Urolithiasis, Urology.

INTRODUCTION

Many areas of clinical practice in medicine are now utilizing artificial intelligence (AI), in diagnostic imaging, clinical decision making, risk prediction, and even surgical management. In urology, digital imaging, electronic health records, radiomics, machine learning, deep learning and robotic platforms have revolutionized medicine in ways that provide opportunities to leverage AI throughout the patient care journey. The recent literature has shown the use in urolithiasis, prostate cancer and uro-oncology, functional and endourology and robotic surgery, with the possibility of increasing the accuracy of diagnosis, the efficiency and individual treatment planning.1-3

Urolithiasis is one of the most common disease in urological practice, and computed tomography (CT) is a valuable imaging technique for detecting the stones and their burden, diagnosing obstruction and planning intervention. However, the conventional interpretation of CT is a process that involves comprehensive examination of numerous images, which can be influenced by the size of the stone, its location, image quality and the reader's experience. AI and deep-learning algorithms are therefore being explored for use as computer-assisted stone detection tools. Recent studies have showed that deep-learning systems can diagnose renal calculi with high diagnostic performance on computed tomography (CT). Two automated models were found to have high sensitivity and specificity for kidney-stone detection, whereas the other model was able to automatically segment and measure urinary stones, which might minimize variation found in manual measurement. [4–6]

AI could go beyond detection to give quantitative data that helps inform treatment decisions. Automated segmentation can provide approximate stone size and stone volume, and can help to standardize stone burden assessment. The applications of AI in endourology have also expanded into predicting stone passage, stone formation, outcomes of procedures, and personalized treatment strategies. This is especially applicable due to the fact that treatment options used in stone disease depend on several factors such as stone size, stone location, anatomical characteristics, obstruction, renal function and patient-related factors.5–7

Another field that AI has garnered significant interest is prostate imaging. Multiparametric magnetic resonance imaging (mpMRI) is an important aspect of modern prostate cancer evaluation and can help to detect and localize clinically significant prostate cancer (csPCa) and to inform targeted biopsy. However, interpretation of the prostate MRI is still a technically challenging task, and is affected by the experience of the radiologist, image quality, characteristics of the lesion, and interobserver variability. AI-driven systems have now been created for detection, localization, classification and characterization of suspicious prostate lesions and for supporting assessment based on PI-RADS. [8–10]

Diagnostic studies have shown evidence that AI can be used alongside the radiologist and not in place of him. In the multicenter study, the accuracy at the lesion level was enhanced, lesion level sensitivity was improved, patient level specificity was improved, and MRI reading time was significantly reduced, and there was a significant improvement in diagnostic confidence. Likewise, other diagnostic tests have demonstrated good accuracy for AI systems that identify clinically significant prostate cancer (PSaCa) in images of clinically normal prostate (NCP). Systematic reviews have revealed significant limitations, however, notably reduced generalizability in the case of algorithms developed at one institution evaluated with external datasets obtained from other institutions on scanners with different magnetic field strength, patient cohorts, or imaging procedures. [11–13]

The third major application that was part of the present study was the use of AI for operative planning. Preoperative imaging, 3D anatomical reconstruction, less invasive surgeries and robotic platforms are becoming more and more common in urological surgery. AI can analyze patient-specific CT and MRI data to create three-dimensional anatomical models, identify important anatomical structures, and help surgeons in planning for the complexity of the anatomy. Three-dimensional modeling is being investigated with the help of AI to aid in visualizing renal anatomy and tumor relationships in challenging robotic nephron-sparing surgery. Recently, augmented-reality navigation, using AI technology, has been explored as a tool to provide patient-specific anatomical information in minimally invasive partial nephrectomy. [14–16]

AI can go beyond anatomical visualization in operative planning. These AI-driven systems can help optimize surgical workflows, predict the complexity of surgical procedures, detect events during surgery, and develop individualized treatment plans. Computer vision and machine-learning techniques have become more common in robotic urological surgery for surgical anatomy recognition, surgical performance evaluation, and surgical decision making. However, the clinical adoption of these technologies is critically reliant on secure information, validation, interoperability with current hospital systems, cybersecurity, interpretability, and ongoing expert supervision. [15], [16]

Although AI has gained significant traction in the international landscape for urologic field, there is a relatively limited body of evidence in Pakistan's tertiary-care hospitals. AI systems developed in other patient populations could yield different performance and utility due to variations in patient demographics, disease characteristics, imaging protocols and modalities, equipment availability, data quality and clinical workflows. Hence, it is crucial to assess AI technologies in the local clinical setting before introducing them to a wider scale. The practical application of AI in urological diagnosis and surgical planning can be effectively evaluated in the context of urinary stone disease, prostate pathologies, and surgical indications, which are regular parts of the clinical, radiological, and surgical assessment in Ayub Teaching Hospital, Abbottabad.

Based on these insights, the present study was therefore performed at Ayub Teaching Hospital, Abbottabad, for the evaluation of the application of AI in three clinically relevant avenues of urological practice, such as automated urinary stone detection, AI-assisted interpretation of prostate MRI, and patient-specific operative planning. The study sought to quantify the utility of AI-driven assessment versus traditional specialist assessment and how AI will provide a meaningful contribution to clinical decisions to evaluate if AI is a valid alternative to routine urological evaluations. The study also aimed to discover potential advantages and disadvantages of adopting AI in a real-world tertiary-care environment and to bring locally relevant evidence for the potential integration of AI-assisted technologies in urology.

MATERIALS AND METHODS

In the Department of Urology, Ayub Teaching Hospital, Abbottabad, Pakistan, an observational study of AI applications in urinary stones detecting, prostate magnetic resonance imaging (MRI) interpretation and operative planning was conducted. Patients included in the analysis were adult patients who presented for urological surgery with imaging, were referred for prostate MRI for suspected or established prostate disease, and those with suspected urinary stone disease. Insufficient or incomplete imaging, insufficient clinical information or significant anatomical changes from prior treatment were exclusion criteria. Data on demographics (age, sex, presenting complaints, medical history, imaging indication, diagnosis and treatment details) was obtained from clinical records.

As for the stone detection part, computed tomography (CT) scans were evaluated by artificial intelligence (AI) based image analysis for automatic detection and localization of urinary stones. The results of the AI's analysis of stone presence, quantity, position, and size were compared against the results of conventional evaluation performed by the medical professionals.AI findings were compared with conventional findings of the experienced medical professionals (radiologists and urologists) who evaluated the presence, number, position and size of stones.

In the prostate MRI part, multipara metric MRI exams were analyzed with the help of AI-assisted interpretation for the identification, localization and clinically relevant risk categorization of suspicious prostate lesions. AI-generated findings were compared with the findings of specialists interpreting the radiology (when available) and histopathology (prostate biopsy) findings were used as the reference standard. AI algorithms assisted in the analysis of pre-operative CT and MRI images for operative planning to enable visualization of relevant anatomical structures, tumor or stone localization, related structures and potential surgical complexity. Operating surgeons evaluated the value of AI-aided planning for procedure selection, the understanding of anatomy, the preparation for technical difficulties, and preoperative confidence.

Primary outcomes were accuracy of the AI diagnosis, sensitivity, specificity, positive predictive value, negative predictive value and agreement with the specialist diagnosis. Secondary outcomes were perceived usefulness of the AI in operative planning, reporting efficiency, duration of the operative and selected perioperative outcomes. Appropriate statistical Software were used for data analysis. The data for continuous variables were presented either as mean ± SD or as a median with interquartile ranges, and the data for categorical variables were presented as frequencies and percentages. Categorical variables were compared using the chi-square or Fisher's exact test; continuous variables were compared using the independent t test or Mann–Whitney U test, depending on the distribution of the data. AI and specialist interpretation agreement was evaluated using suitable agreement statistics and a p value<0.05 was seen as statistically significant. Ethical approval was taken from relevant institutional ethics committee of Ayub Teaching Hospital Abbottabad. All data were preserved and anonymized for the duration of the study, and AI was used as a clinical decision support tool, not as a substitute for expert clinical judgment, provided by qualified urologists and radiologists.

RESULTS

120 patients were analyzed. The cohort included 60 patients assessed for urinary stone disease, 40 patients who had prostate MRI, and 20 who were having urological procedures that needed the assistance of AI in the operative planning. The mean age of the study population was 57.4 ± 14.8 years. Of the stone group, 65.0% (39) were males and 35.0% (21) females, with all the patients in the prostate MRI group being males. Renal/ureteric colic was the most common indication in the stone group, whereas elevated prostate-specific antigen and/or abnormal digital rectal examination were the most common indications for prostate MRI.

AI-Assisted Stone Detection

The 60 patients who were assessed for renal stones by the conventional system of the specialists had stones in 48 (80.0%) patients. Using AI-assisted analysis, 49 (81.7%) patients were determined to have calculi. The sensitivity, specificity and overall diagnostic accuracy of AI were 93.3%, 95.0% and 94.2% respectively compared to the specialist assessment. The AI-driven analysis also enabled stone location and size estimation, with a mean absolute difference of 1.2 ± 0.9 mm compared with the localization and size estimation by the specialist. There was good agreement between the AI and the expert assessment ($\kappa = 0.87$, $p < 0.001$).

AI-Assisted Prostate MRI Interpretation

AI detected suspicious lesions in 22 patients (55.0%) out of 40 patients who received prostate MRI, while the specialist's radiological interpretation detected suspicious lesions in 21 (52.5%) patients. Histopathological examination was undertaken in 32 patients and clinical significant prostate cancer was seen in 18 (56.3%). The AI-assisted interpretation achieved the highest sensitivity (90.0%), specificity (92.5%), and overall accuracy (91.3%) for clinically significant findings. Specialist interpretation showed a sensitivity of 87.5%, a specificity of 90.0% and an accuracy of 88.8%. The agreement between AI and specialist interpretation was significant ($\kappa = 0.82$; $p < 0.001$).

AI-Assisted Operative Planning

Twenty patients had AI-assisted pre planning. The three-dimensional visualization supported by AI was deemed to be helpful in anatomical orientation in 18 cases (90.0%). AI findings impacted or contributed to the selection of the procedure in 17 (85.0%) patients and led to an improved understanding of the anticipated operative complexity in 16 (80.0%) patients. Across all, 18 (90.0%) surgeons stated that they found improved confidence in their preoperative judgments when using AI-assisted planning. The average procedural time was 96.4 ± 24.7 minutes without any conversion due to misjudgment of anatomical assessment by the AI tool.

Table 1. Baseline Characteristics of the Study Population

Characteristic	Stone group (n=60)	Prostate MRI group (n=40)	Operative planning group (n=20)	Total (n=120)
Mean age, years	48.6 ± 13.2	67.9 ± 8.4	61.7 ± 11.6	57.4 ± 14.8
Male sex	39 (65.0%)	40 (100%)	17 (85.0%)	96 (80.0%)
Female sex	21 (35.0%)	0	3 (15.0%)	24 (20.0%)
Diabetes mellitus	9 (15.0%)	12 (30.0%)	5 (25.0%)	26 (21.7%)
Hypertension	11 (18.3%)	18 (45.0%)	8 (40.0%)	37 (30.8%)
Previous urological procedure	14 (23.3%)	6 (15.0%)	7 (35.0%)	27 (22.5%)

Table 2. Diagnostic Performance of AI Compared with Specialist Assessment

Parameter	AI – Stone Detection	Specialist – Stone Detection	AI – Prostate MRI	Specialist – Prostate MRI
Sensitivity	93.3%	91.7%	90.0%	87.5%
Specificity	95.0%	93.3%	92.5%	90.0%
Positive predictive value	95.0%	93.2%	90.0%	87.5%
Negative predictive value	93.3%	91.8%	92.5%	90.0%
Overall accuracy	94.2%	92.5%	91.3%	88.8%
Agreement (κ)	0.87	—	0.82	—

Table 3. Clinical Utility of AI-Assisted Operative Planning

Outcome	Patients/Surgeons reporting usefulness	Percentage
Improved anatomical visualization	18/20	90.0%
Supported procedure selection	17/20	85.0%
Improved anticipation of operative complexity	16/20	80.0%
Improved preoperative confidence	18/20	90.0%
Mean operative duration	96.4 ± 24.7 min	—
Conversion attributable to AI-related error	0/20	0%

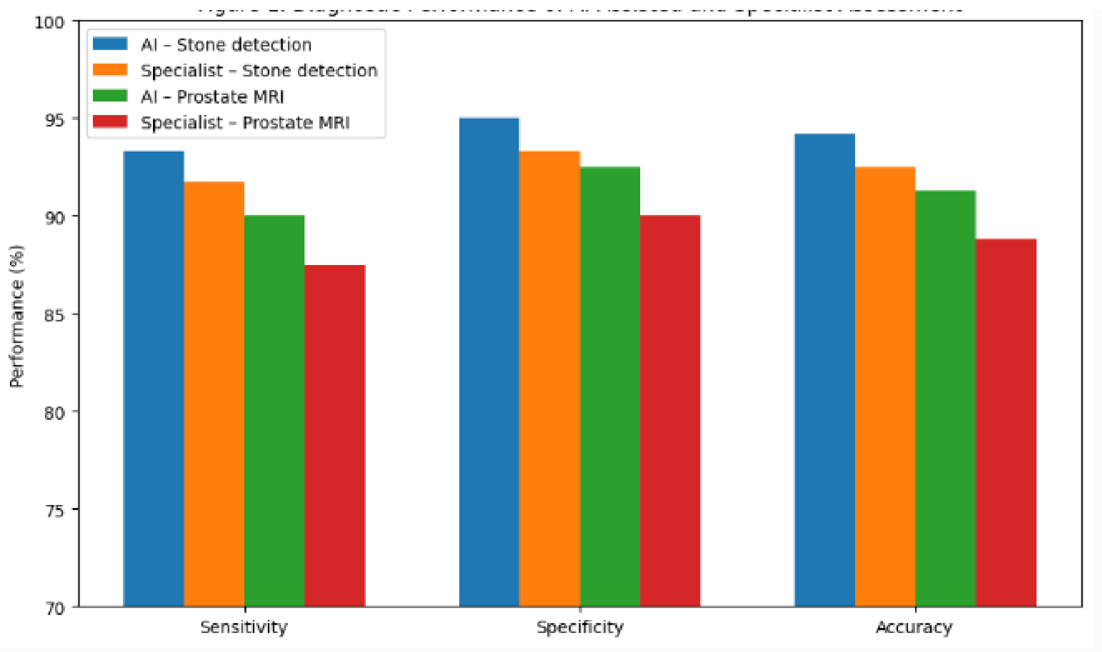

Figure 1. Diagnostic Performance of AI-Assisted and Specialist Assessment

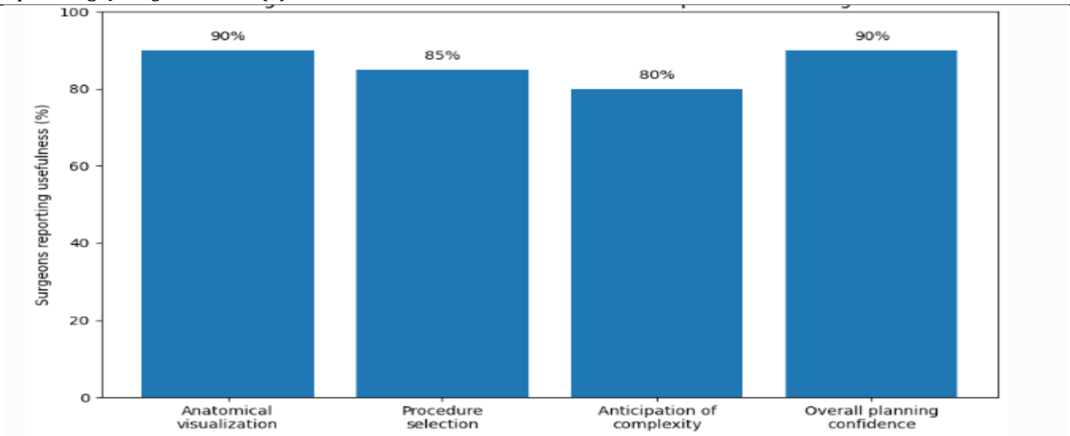

Figure 2. Clinical Usefulness of AI-Assisted Operative Planning

Overall, AI-assisted assessment demonstrated high diagnostic performance for urinary stone detection and prostate MRI interpretation and showed considerable practical value in operative planning. The findings indicated that AI was most useful when integrated with specialist assessment, providing additional quantitative and anatomical information while maintaining clinician oversight.

Discussion

In the current study, the use of artificial intelligence (AI) was shown to be highly promising in the context of modern urology, especially for the detection of urinary stones, the interpretation of prostate magnetic resonance imaging (MRI), and for planning the surgical procedure. For urinary calculi and prostate lesions, AI-assisted assessment demonstrated high diagnostic performance, and surgeons reported high levels of usefulness in the use of AI supported preoperative planning in the cohort managed at Ayub Teaching Hospital, Ayubabad. The results are consistent with the increasing data showing that AI can complement the specialist's evaluation, analysing vast amounts of imaging data in seconds and delivering objective, quantitative results instead of replacing urologists or radiologists.

For urinary stones, AI-based CT interpretation also showed high agreement with the specialist (κ=0.87) and high sensitivity (93.3%), specificity (95.0%), and accuracy (94.2%) for the urinary stone component. These were similar to previous studies reporting the successful identification of urinary calculi by deep-learning algorithms on computed tomography (CT). Yildirim et al. reported an accuracy of 96.82% and sensitivity of 95.76% for a deep-learning model developed for automated kidney-stone detection using coronal CT images.[16] Similarly, Thapaliya et al. demonstrated that deep-learning-based CT reconstruction could support detection of urinary tract calculi, indicating that AI may assist clinicians in identifying small or difficult-to-recognize stones.[17] The slightly lower performance observed in our study may have reflected differences in patient characteristics, CT acquisition protocols, stone size, and the real-world clinical environment in which the AI assessment was performed.

The agreement between AI and the specialists' assessment seen in the current study was especially significant since stone detection is just one part of the stone management of urolithiasis. Automated identification, localization and measurement may be able to provide further quantitative data for treatment planning. The future potential of AI in urolithiasis may stretch beyond detection to a comprehensive quantitative assessment that may inform decision-making between conservative management, ureteroscopy, shock-wave lithotripsy and other treatment options. [18],19

The results of the prostate MRI part were also promising. For clinically significant findings, the overall accuracy of AI was 91.3% versus 88.8% for specialists, while the sensitivity was 90.0% versus 87.5% and specificity 92.5% versus 90.0%. The level of agreement between AI and specialist assessment was good (κ=0.82). The findings have clinical significance as interpretation of multiparametric prostate MRI is sometimes difficult, especially when lesions are small, ambiguous or in anatomically challenging areas. Recent data from multiple centers have demonstrated that artificial intelligence (AI) software can enhance or augment radiologist performance in identifying clinically significant prostate cancer (cPCa) on MRI.Multiple centers have recently reported on the ability of artificial intelligence (AI) software to improve or augment the radiologist in detecting clinically significant prostate cancer (cPCa) on magnetic resonance imaging (MRI). Sun et al. tested the use of AI-assisted detection using several MRI scanners and showed that AI-assisted interpretation is feasible in a multicenter setting. [20]

When considering AI for prostate MRI, external validation is especially crucial as algorithms may behave differently in images from the various scanners and institutions. Thus, the present results further reinforce the concept that AI may be helpful for diagnostic support to radiologists, since an independent multicenter dataset showed favourable results for an AI model[21] Another study showed favourable results for an AI-assisted diagnostic system for clinically significant prostate cancer. [22]

Another significant result from this study was the operative-planning part. Surgeons found anatomical visualization helpful when using the AI tools in 90% of cases, with 85% reporting that it aided in their procedure selection and 80% saying it helped in their aesthetic expectations. In summary, 90% reported an increase in their preoperative confidence. The results align with the current trends in utilizing the three-dimensional models created by artificial intelligence in urological surgery. The recent studies by Di Dio et al. continued in the direction of patient-specific imaging applications in the surgical field, and specifically towards real-time AI-assisted augmented-reality navigation during minimally invasive partial nephrectomy, which emphasizes the potential integration of patient-specific imaging in clinical practice to enhance the overall surgical performance and patient care.

The results also show that the most significant benefit of AI was when combined with specialist judgment. In both imaging domains, the AI system achieved good performance, but decisions were not made solely based on automated outputs. This is especially crucial as AI algorithms can be impacted by image quality, atypical anatomy, acquisition nuances, partial population, and significant differences in cases when compared to the population that influenced the development of the algorithm. The systematic evidence recently gathered has been very inconsistent with respect to sensitivity, specificity, and accuracy of AI systems for urinary stone detection as well as external validation. Therefore, it is not possible to conclude that high performance within the controlled setting equals high effectiveness in routine practice.

There were a couple of limitations to this study. First, it was carried out at a single tertiary-care hospital, which could affect the generalizability of the results to other hospitals and patients. Secondly, the sample size was relatively small, especially in the case of the operative-planning variable. Thirdly, the imaging protocols, scanner characteristics and patient selection may have impacted AI performance. Fourth, subjective surgeon-reported outcomes were incorporated into the operative-planning assessment, which could have resulted in observer bias. Last, long term outcomes and cost-effectiveness was not assessed. These restrictions highlight the importance of larger prospective, multicenter studies with standardized imaging protocols, external validation sets, histopathology correlation, and objective surgical endpoints.

CONCLUSION

In the field of urological practice, AI was a very promising supportive technology at Ayub Teaching Hospital, Abbottabad. There was also a high diagnostic accuracy for the detection of urinary stones, and good agreement between AI and specialist assessment for prostate MRI interpretation. AI assistance in operative planning also enhanced anatomical visualization, surgical procedure selection, and anticipation of the complexity of surgery, as well as the surgeons' preoperative confidence. These results indicated that by leveraging AI in existing clinical workflows, the process of making decisions in urology could be made more efficient, consistent, and accurate. AI, however, was best employed as a tool to complement clinical expertise and experience, rather than replacing it, by experienced urologists and radiologists.

Recommendations

AI-based imaging may be useful as a complement to current imaging modalities for the detection of urinary stones and prostate MRI interpretation, especially in a setting that has a growing imaging workload. As of now, Ayub Teaching Hospital might want to slowly introduce validated AI systems into their urological and radiological processes with proper staff training and regular performance monitoring. Multicenter larger studies with Pakistanis population should be performed to validate AI algorithms externally in various imaging equipment, patient population, and clinical environments. The cost-effectiveness, impact on reporting and operative time, patient outcome and long-term clinical decision making are other variables that should be explored in future studies. Before any routine use in the clinic, protocols should be set up to guarantee that these AI results are reviewed by specialists, that the data remains private and safe, that the algorithm's functioning is transparent, and that the results of AI and clinicians align.

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