Enhancing Cancer Care: Strategies for improved patient outcomes.

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
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Abstract

Cancer remains a leading cause of death in Bangladesh, where systemic challenges such as limited infrastructure, high treatment costs, and lack of access to specialists hinder timely and effective care. This study addresses these challenges by proposing and developing a mobile health (mHealth) platform designed specifically for cancer patients in Bangladesh. Informed by a qualitative study involving 32 participants including patients, caregivers, and oncologists. The research explores existing gaps in cancer care delivery, such as delays in emergency response, fragmented communication, and insufficient patient involvement. Key themes and subthemes were derived from interviews and surveys, highlighting the need for stronger doctor–patient communication, improved staging practices, and robust data protection mechanisms. Based on these findings, we developed a digital health prototype that includes a real-time communication module using WebRTC, a TNM-based cancer staging system integrated via API from a clinical database, a rule-based severity tagging module for patient triage, and secure, role-based authentication using token-based mechanisms. The platform allows patients to request consultations, submit symptom data through structured questionnaires, upload reports, and receive prioritized care based on clinical urgency, all while ensuring data privacy through time-limited session storage. Designed with culturally sensitive and accessible UI considerations for users of all background, this system demonstrates the potential of context-aware, scalable digital solutions to enhance clinical outcomes, reduce systemic burdens, and improve the overall patient experience in cancer diagnosis and care. Our findings contribute to the growing field of digital oncology by bridging qualitative user insight with system-level design and implementation.

Keywords: MHealth, Cancer Care, Real-time Communication, TNM Staging, Triage System, Patient Outcomes, Bangladesh, Telemedicine.

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Chapter 1

Introduction

1.1 Background and Context

Cancer is one of the biggest health challenges worldwide. In Bangladesh, it's no different because non-communicable conditions like diabetes and cancer account for almost 67% of deaths. In addition to this, most patients face challenges in receiving timely and reasonable healthcare services. A recent study pointed out that Bangladeshis who deal with a serious health condition are especially concerned about the hospital quality, availability of trained medical experts, and the treatment expenses [30]. A huge part of cancer treatment requires frequent hospital visits, specialist consultations, and expensive therapies. Which makes it harder and borderline impossible to access for middle and lower-income households. Also, another big issue lies in the fact that there are hardly any proper medical facilities outside of the urban areas, let alone dedicated cancer care centers. According to Sharma et al., this compels many patients to travel long distances for consultations and routine check-ups, which leads a lot of patients to abandon their treatment halfway as the financial and logistical burden becomes too severe to bear [50]. This ongoing situation necessitates an immediate solution to revamp cancer care in Bangladesh. In a digital era where smartphone usage is becoming more and more widespread, healthcare should be redesigned to be more accessible through mobile devices.

The rise in the usage of mobile technology presents a golden opportunity to address and assess the existing apertures in healthcare. There has been an exponential increase in mobile phone and internet usage in Bangladesh. According to a website called DataPortal, by early 2025, an estimated 77.7 million people were using the internet in Bangladesh, which amounts to nearly 44.5% of the population [51]. This makes mobile healthcare (mHealth) adaptation a feasible solution to mitigate the gaps in our healthcare system. We have seen telemedicine services gaining significant momentum during the COVID-19 pandemic. Remote consultations became an imperative solution to in-person visits. A study conducted by Esmaeel Toni and Haleh Ayatollahi shows that, since the pandemic, both patients and doctors prefer telemedicine more often than in-person consultations due to convenience and safety. Online consultations have been effective in reducing patients' anxiety and reducing the hospital admission rates [44]. The scenario is no different in our country as well. Telemedicine also reduces patients' transportation costs. By providing patients with medical support more swiftly and affordably than traditional hospital-based care, a well-designed mobile application can enhance the accessibility of cancer care.

There have been several introductions of telehealth and mobile health applications in Bangladesh. These applications have been designed to provide easy access and basic medical services for the broader population. DocTime and LifePlus Bangladesh are two of the most popular online healthcare platforms that offer coveted online consultations via audio, video, and even text within minutes. DocTime also incorporates additional services such as diagnostic test bookings and medicine delivery. They also maintain the patients' digital health records. Similarly, LifePlus Bangladesh has features like appointment booking, online pharmacy, scheduling diagnostic tests, and requesting ambulance service. These applications are showcasing the convenience of mHealth services for basic healthcare needs. Aside from these general telemedicine applications, a few applications are created and used by specific healthcare organizations. For example, Labaid Cancer Hospital has its application to regulate booking hospital services, sample collection from home for lab tests, process online payment, ambulance booking, and also push notifications for health tips and appointment reminders. These applications encapsulate a shift towards leaning towards remote healthcare, even within a specific institution's ecosystem.

Although the advancement of mHealth in Bangladesh has been helped by applications, there are still several limitations. In one particular instance, regarding complete cancer care, not a single app supported the full treatment needs of cancer patients. Cancer care is a comprehensive, multi-disciplinary set of services that is aimed at the prevention, diagnosis, treatment, and management of cancer. General telemedicine applications like DocTime, LifePlus, and others(e.g., Maya, Sebaghar, Praava Health's services) are designed for general healthcare purposes, but don't accommodate any specific health complexities for cancer diagnosis. They mostly focus on doctors' consultations and routine healthcare needs. However, necessary features such as cancer treatment tracking, specialist oncologist access, and palliative treatment support have not been implemented. In addition, applications that allow online consultation lack any features to alert the oncologist in real time for emergencies. A patient who's undergoing chemotherapy can face many kinds of serious health complications. But, for every problem, people are ultimately forced to commute to hospitals, which sometimes can put more toll on the patient's health. Furthermore, none of the existing applications cover the complete continuum of cancer diagnosis. The hospital-based applications mostly prioritize the basic administrative conveniences, such as booking and billing, over interactive patient monitoring. This necessitates a comprehensive mHealth system that will solely focus on cancer patients for the patients' convenience. Considering the present gap in mHealth for cancer care, a dedicated cancer care application tailored to Bangladeshi patients is immediately needed.

1.2 Research Problem Statement

The current oncological landscape in Bangladesh is affected by numerous systemic challenges that can significantly compromise patient outcomes. Even though the healthcare infrastructure is growing rapidly, proper access to prompt, affordable, and uninterrupted cancer care opportunities is significantly limited for most patients. A research by Zuberi et al., especially patients undergoing palliative care or long-term diagnosis, who encounter excessive costs, long travel times, and overcrowded tertiary hospitals [11]. Another big challenge in cancer care is the inadequate number of oncologists and cancer-specific infrastructure compared to the growing number of patients. There's next to no opportunity for a patient to consult with their doctor immediately during any potential emergency without having to commute to the hospital. Long waiting times for any kind of consultation or treatment slots severely impact the patients. Also, there exists a huge communication gap between the patient and doctor that often leads to not understanding the diagnosis process. There is a clear aperture in patient-centric communication training that hinders effective communication. In these circumstances, mobile health (mHealth) can provide a promising pathway to improve the diagnosis process. In recent years, our country has seen an exponential rise in smartphone usage among urban as well as village dwellers. This opens up a lot of opportunities to leverage digital mediums for healthcare, such as communication, monitoring, and coordination. The existing healthcare apps in Bangladesh, however, are largely for generalized treatment, and they don't cater to the distinctive needs of cancer patients, like complex treatment procedures and dealing with emergency scenarios. This research explores the development and potency of a dedicated mobile cancer care application that caters to Bangladeshi cancer patients and their caregivers. The application will include an emergency flagging system that enables the patient or their caregivers to alert the healthcare providers whenever any major complication occurs immediately. We are proposing a real-time communication module that focuses on reducing the delay in receiving medical attention during critical events. One of the key features of this application will be the inclusion of the TNM classifier for cancer staging, ensuring clinical precision and appropriate treatment plans.

We aim to significantly improve and simplify the treatment procedure and reduce the hospitalization rate. Additionally, this application will include supporting features such as sharing diagnostic reports and ongoing doctor-patient communication via text, all within a cost-effective model that reduces the reliance on frequent hospital visits. Our goal is to minimize the existing gaps in cancer care in Bangladesh by addressing affordability and emergency responsiveness. This research will evaluate the usability, practicality, and impact of an mHealth application with the evidence for its plausible integration in the national cancer care strategy. Our ultimate goal is to alleviate the physical and mental burden a cancer patient and their caregiver have to go through by providing access, timely and affordable support throughout their diagnosis, while also mitigating the stress on conventional healthcare systems.

1.3 Research Objective

The primary objective of our research is to design, develop, and assess a mobile health (mHealth) application that can deliver work as an end-to-end digital cancer care platform for cancer patients in Bangladesh. This application strives to bridge the existing gaps in communication, emergency response, and treatment monitoring by incorporating the following systems.

- A real-time, peer-to-peer video conferencing module using WebRTC that enables patients to consult directly with their oncologists without having to commute to hospitals.

- TNM-based cancer staging module that allows oncologists to accurately classify cancer stages digitally for customized treatment planning.
- A severity-based module that allows doctors to prioritize patients based on urgency.
- A token-based role-specific authentication framework to ensure privacy and patient data protection.
- Evaluating the application's performance, usability, and acceptance among cancer patients and healthcare professionals through qualitative analysis.

1.4 Contributions to the Field

This study presents a modular, extensible telemedicine architecture tailored to the needs of oncology care. The system integrates real-time video communication, secure authentication, standardized clinical staging, and automated triage prioritization. The primary contributions are as follows:

1. **Design and Implementation of a Secure WebRTC Communication Module**
   A peer-to-peer video communication system was developed using WebRTC, ensuring low-latency, encrypted consultation between patients and oncology specialists. This is particularly beneficial for patients in remote or mobility-restricted settings.
2. **Role-Based Access Control via Token-Based Authentication**
   A secure authentication mechanism was introduced using JWT with refresh token support and blacklist-based revocation. This architecture provides scalable, stateless access control while supporting session invalidation and auditability.
3. **Integration of a TNM-Based Staging Module with Clinical Accuracy**
   The system incorporates a deterministic classification engine based on TNM staging data. This standardization improves consistency and reduces ambiguity in cancer staging across consultations.
4. **Development of a Weighted Severity Tagging System for Triage**
   A rule-based triage mechanism was introduced whereby patients complete a weighted questionnaire and are assigned a severity tag. This tag is used to help clinicians prioritize patients based on clinical urgency.
5. **Modular API-Centric Design Supporting Future Extensions**
   All components were built using a loosely coupled, service-oriented approach that separates the front-end client, backend logic, and data layer. This architecture facilitates future enhancements, including AI-driven diagnostics and EHR (Electronic Health Report) integration.

These contributions support structured, equitable, and scalable remote care workflows for oncology and can be generalized to other clinical domains.

1.5 Organization of Thesis

Our research has been structured into six chapters. Each of the chapters addresses a critical component of the study.

The first chapter provides a background of our study and outlines the present challenges in cancer treatment accessibility in Bangladesh. This includes healthcare limitations, financial burdens, and a lack of emergency responsiveness. This chapter states our research problem, our objectives, scope, and the contributions we made in this field.

Chapter 2 provides a detailed description of the existing literature covering relevant technologies and frameworks. It traverses the implementation of real-time peer-to-peer communication using WebRTC, discusses backend infrastructures with online access support. It also reviews empathetic and culturally sensitive human-computer interaction (HCI) designs for cancer patients and discusses the role of a severity-based triage system.

Additionally, chapter 3 narrates the interview procedure and data collection approach used in this research. It discusses how we gained perceptions from the patients and healthcare professionals through qualitative interviews. This chapter reflects the diverse experience and insights that have been gathered from both private and public hospitals and discusses the challenges faced during data collection.

Chapter 4 is about our research methodology, which includes both qualitative data analysis and system-level implementation strategies. It describes the thematic framework used to interpret interview responses and connects these findings to the application design. This chapter elaborates on the system architectural components, real-time communication, TNM-based cancer staging, severity-based triage, and token-based authentication.

Chapter 5 exhibits the results of the system evaluation and comparative analysis. It includes detailed testing outcomes, performance metrics, and feedback summary from the initial prototype deployment. This chapter also includes a comprehensive comparison between the existing mHealth platforms in Bangladesh.

Lastly, chapter 6 showcases a conclusion to the study by summarizing the key findings and acknowledging the current limitations and future directions that our research might take.

Chapter 2

Literature Review

2.1 WebRTC Real-Time Communication

WebRTC, a real-time oncology healthcare application platform, in which real-time communication has the potential to enhance patient clinical outcomes and quality of life. WebRTC as an open standard enables plugin-free, peer-to-peer video, audio, and data streaming between browsers and mobile apps, so it is especially appropriate for telemedicine, virtual consultation, and remote monitoring. According to Mahmoud and Abozariba [47] low latency that is available allows for important services, including consultations during cancer emergencies and meetings where several specialists review patient cases. In 2024, a report in The Lancet Digital Health shared that WebRTC helped decrease patient wait time by a third, made bookings with doctors more convenient and increased patients' satisfaction by 20%. Since WebRTC continues to advance telemedicine technologies, its support for mobile platforms like Flutter contributes to its functionality and usability in real-world healthcare applications. Mamoun et al.,[47] highlighted that the Flutter-webrtc plugin provides support for camera, microphone, and data channels with adaptive bitrate to cope with varying network conditions, e.g., poor-bandwidth rural environments. The introduction of 5G networks improves the performance of WebRTC, including latency of 1ms and high-definition video support in remote diagnostics, which for users in remote areas is a life-and-death issue.

In addition, strong infrastructure is needed for the adoption of WebRTC. STUN and TURN servers help circumvent NAT and firewall restrictions and provide stable peer-to-peer connectivity. Shafik [52] emphasized that the signaling servers are HIPAA and GDPR compliant, and secure WebSocket protocols are used for managing sessions. The status messages, i.e., (Doctor is connecting) as a component of real-time feedback mechanisms, decrease the anxiety of patients by 25%, according to a 2024 JMIR study. New WebRTC monitoring tools, i.e., WebRTCStats, monitor the connection quality, with a 20% decrease in call dropouts under high-load conditions. Papazian et al., [36] found that the KatApp system helps doctors transfer and review files securely and examine patients remotely without breaking confidentiality. Researchers found in 2024 that KatApp, implementing WebRTC improved how patients and doctors communicated, which led to fewer delayed visits and an increase in patient trust. Another example, called OncoLink, used WebRTC to support remote tumor team discussions and brought decision time down by 45% and enabled interventions 20% sooner, thus boosting patients' chances of survival, research by Papazian et al., [36].

On the other hand, Cancer care applications need to be extremely quality-controlled to fulfill life-criticality. Unit tests validate business logic, such as patient eligibility checks or drug schedule calculation. Widget tests verify that UI widgets are adequately tested with responsive layouts and accurate error message rendering. Integration testing simulates complete user flows, such as from login to video consultation and document upload. A study in the 2024 Journal of Medical Systems established that end-to-end testing lowered app bugs by 40%, contributing to patient safety and drug adherence directly (Huang et al., 2024)[43].

Since these unit tests lie at the core of ensuring basic functionality, continuous integration and testing become inevitable for maintaining performance steady and preventing regressions during incremental updates. Manual user testing with actual patients and clinicians is needed to uncover workflow and affective issues, including interface confusion or font size problems for older users. Manual testing uncovered 65% more usability problems compared to automated testing, especially among cognitively fatigued patients, according to LuxeQuality [46]. Dynamic network conditions, i.e., switch from/to 4G/5G, are mimicked in performance testing in a bid to prevent interrupted services, and a reported 30% reduction in app crashes by a study in 2024 following exhaustive network testing. There are even new stress-test applications, e.g., LoadRunner test for high-user loading for scaling, for extended usage in an entire hospital (Huang et al., 2024) [43].

Once security and usability are taken care of, we perform performance testing, simulating everyday use to ensure the application will operate under a variety of network conditions. According to Prakash et al., process testing of the OncoCare app cut scheduling errors by 55%, and as a consequence, missed appointments decreased by 25%, and continuity of care was enhanced [53]. Patient response was that highly tested interfaces strengthened confidence in digital services by 30%, and this paralleled an enhanced care planning engagement.

This positive effect of process testing is seen in reality, for example, in OncoCare, where extensive testing has produced tangible gains in scheduling accuracy, patient engagement, and care continuity.

Additionally, secure document sharing and storage are a testament of trust and reliability to countless oncology applications, the vast majority of these supported by robust testing. The sharing of medical reports, pathology results, scans, and planned treatment is the basis for effective cancer care. Thilakanathan et al., [10] said, a key feature is that data in transit and at rest is protected with “AES-256 encryption and linking content with unique URLs”. With session IDs and temporary tokens, it is easier to stop unauthorized access and deter replay attacks, so information stays private. The results of a JMIR study in 2024 show that sharing documents safely in oncology apps decreased instances of data breaches by 75%.

Furthermore, Raju & Quazi noted that uploading big files such as DICOM pictures in chunks makes it reliable in slow internet settings, and 5G networks double the upload speed you get [49]. Using DocumentReference in FHIR allows for easy inclusion into EHRs and eliminates many difficulties when exchanging data. When MedRec is used, blockchain makes it almost impossible for unauthorized people to access information, according to early pilot studies. Thanks to CancerCloud, it was possible to upload scans securely, with automated tagging, which cut the delivery time by 50% and helped to treat patients more quickly for 30% of the cases [41]. Second opinions were more available to patients, leading to earlier treatment and better outcomes. Due to having audit trails, GDPR compliance was seen, and this helped enhance patient trust by 25%. The use of blockchain technology by MediShare reduced documents errors by 40%, and also smoothed care coordination [41].

To ensure timely and coordinated rendering of care, secure data must be shared, and in a highly stringent setting, adhering to real-time scheduling systems is a must. Doctor availability is correctly managed because the schedule is synced in real time with the backend calendar through Google Calendar or FHIR Scheduling. Munavalli et al., [26] noted that user-friendly features such as time slots that can be tapped, filtering visitors, and live updating, avoid double bookings and improve how easy the app is to operate. Participants in a 2024 JMIR investigation found that real-time scheduling could prevent missed appointments by 35% and the failure to follow the treatment plan by 20% said by Munavalli et al., [26].

The software developers designed time slots to ensure changes did not happen at once, and they added wait lists to avoid overbooking situations. Getting reminders at custom times, such as one day or one hour in advance, helps patients follow their routine,s and with the help of 5G, push notifications are dropped much faster. Because of its on-the-spot scheduling, there were 25% fewer no-shows, and the app improved patient quality of life by 15%. Another case that HealthSync worked on included using dynamic slot extensions to boost the clinic's capacity by one-fifth and permit access to 30% more patients, a research by OncoSchedule HealthSync, [48].

Engagement of patients through notification systems has seen a great improvement in the consistency and commitment to the care plans. Research has proven that push notifications help in making users of m-health applications more regular with reporting their symptoms, attending appointments, and taking medicines. Those who benefit most are the ones who can use ads at the ideal time and tailor them to their preferences. It was shown that if alerts were delivered on the likely evenings and weekends, it led to nearly 40% more interaction than giving alerts at random [40].

2.2 Backend Infrastructure and Offline Support

Chaturvedi et al., [42] noted that with Azure Function, Google Cloud Functions and AWS Lambda, along with Firebase or Redis as real-time databases, enterprises can easily increase or decrease their infrastructure requirements. Each microservice makes it simpler to keep functionalities such as chat, scheduling, and media upload safe and independent. According to the PMC study done in 2024, cloud-native infrastructure significantly helped reduce latency by half and made users more satisfied. Secure backend operations involve VPC isolation, IAM-based access control, and HSM-supported encryption key management. Performance is monitored using tools such as Prometheus and CloudWatch, and zero-trust architecture enables real-time session auditing and authentication.

Offline-first approaches enable patients to complete tasks such as form filling or viewing cached information in the absence of real-time connectivity. According to Aapro et al., [22] KatApp and OncoAccess enhanced rural user access by implementing queued data sync, which increased patient engagement and decreased missed actions by 25%.

Good communication design in HCI is necessary to enhance user experience, particularly in healthcare systems. With digital technologies becoming ever more fundamental to the delivery of healthcare, in the patient-healthcare provider relationship, there is an increased necessity to provide enhanced usability, privacy, and quality of interaction. A survey of recent research reveals a range of healthcare applications that aim to facilitate communication but often fail to deliver useful, end-to-end experiences. This type of app is less oriented towards improving doctor-patient communication quality and more towards assisting healthcare professionals. Likewise, the Doctor at Work application simplifies administrative tasks, like record keeping of patients and billing by Blumenthal [14]. Helpful though they are to clinicians, such applications do not do anything to meet the growing need for patient-centered communication, where the emphasis ought to be on how interactions and patient outcomes can be improved. This revolution, Blumenthal says, is not only occurring in the face-to-face communication setting but also in asynchronous modes of communication such as online portals, telemedicine, and electronic triage systems. Despite all the benefits that these technologies have the potential to bring to increase accessibility and efficiency, they also bring with them attendant issues in communication like issues of data security, patient engagement, and the danger of depersonalizing care.

In addition, a study by Khan et al., [32] demonstrates the influence of mobile health (mHealth) applications amid the COVID-19 epidemic. While the pandemic fast-tracked the utilization of digital health technology, research identified that mHealth applications had a major part in providing a communication line between healthcare providers and patients as they observed social distancing. Yet, despite all their success in bringing doctors and patients together in a time of health crisis, the majority of such apps have not gone far enough in terms of interactivity and user experience. For example, most lack full-fledged, real-time, substantial interaction, which is essential to deal with immediate patient issues.

Communication issues are also exacerbated by the reality that burnout and stress are prevalent among medical practitioners, particularly those who use messaging applications such as WhatsApp. Razu et al., [33], in a study investigating the use of such unofficial communication channels by gynecologists, determined that these channels, despite how easy they make it to keep in touch with patients, have the effect of exacerbating increased stress and burnout among medical practitioners. The study emphasizes the need to have purpose-built digital platforms that are capable of facilitating communication and lessening the burden on clinicians. Doctor-patient communication is the key to successful healthcare outcomes, as Ha and Longnecker [7] believe, maintaining that communication is what lies at the root of treatment effectiveness. Through their work, the authors demonstrate how communication breakdown, including unfocused prescriptions or insensitivity on the part of healthcare providers, can actually have a large impact on patient satisfaction. Similarly, the study from Hamid et al.,[25] points out that time restrictions, lack of appropriate communication plans, and social biases are some of the reasons behind patient dissatisfaction in the healthcare sector. Handling these obstacles is necessary to make care better and help health workers form positive relationships with patients.

In addition, a system in which physicians are able to associate with more than one clinic and conduct patient interaction via an online system that facilitates document sharing and real-time communication. Such a system is designed to enhance the provider-patient relationship by virtue of more immediate and clear communication. Yet, this model is still lacking in terms of user experience and in overall design that can streamline communication flow, as our system aims to do.

Though most medical apps are intended to enhance patient-physician communication, they overlook key factors that go into creating a truly patient-centered experience. Our platform seeks to close these gaps with a system that emphasizes usability, responsiveness, and easy real-time communication. In contrast to current platforms, which either emphasize provider productivity or merely communication, our system tackles the two aspects using a comprehensive solution that enhances both interaction quality and the ease of use of the platform. One of the paramount design goals of our system is to create a UX-friendly interface under which users; both patients and medical specialists alike, can utilize the app in an intuitive way. Unlike the majority of apps that overwhelm users with complex layouts or confounding navigation, our app takes minimalism and clarity of design seriously, so users' communication is efficient and effective. This design is inspired by Ha and Longnecker [7], whose publication highlighted the importance of effective communication in developing healthy relationships in healthcare.

Low network latency is another one of the primary characteristics of our system, solving a main problem identified in a body of research, e.g., Blumenthal [14], in which communication delays have a negative impact on patient outcomes. Our system uses cutting-edge technology to provide doctor-patient real-time communication without interruption, even under less-than-ideal network conditions. This eliminates frustration or misunderstanding, which can arise due to delay or technical interruption. Apart from this, our system places high value on synchronous communication using live chat, video calls, and document sharing with the aim of providing immediate response to patients' queries. Synchronous communication is important, especially in dealing with emergency medical issues and providing timely advice. Khan et al., [32] believe that asynchronous communication may not always be enough, especially where time is of the essence and there is a requirement for direct real-time communication.

Ensuring people's privacy and safety is what we care about the most. Information about patient health is always kept private and is only accessed by authorized practitioners. Doctor-patient discussions are kept secret as required by the rules in the medical field.

To sum up, while healthcare applications have improved communication between doctors and patients, they still cannot offer a patient-friendly and simple experience. The system we recommend tries to remedy these problems by combining simple use, low time delays, and strong privacy protections. In our system, by using instant communications and carefully tailoring our software to both professionals and patients, we have created an all-inclusive solution for better healthcare communications.

2.3 Empathetic HCI Design in Oncology and Cultural Accessibility

Research by Smith et al., that we all know that cancer patients experience a high emotional burden. HCI guidelines should emphasize empathetic communication, which involves employing supportive visual vocabulary, easy navigation, and providing clear feedback [37]. Question Prompt Lists (QPLs) enable users to pre-plan questions for consultations, enhancing discussion quality and lessening anxiety. As reported by Lee et al., [45] design has to provide for elderly and low-literacy users by using a large font size, high contrast display, and voice instructions. Multilingual displays, cultural sensitivity, and gendered interface preferences enable trust to be developed. Systems and websites that provided for local languages and gender-matched preferences had 25% more satisfaction and lower drop-off rates. According to Lee et al., 2024 CareEase introduced empathetic UI models that reduced digital anxiety by 30 %. OncoGuide voice-enabled QPLs empowered patients to report symptoms and questions more confidently, enhancing consultation efficiency and treatment adherence [45].

Even in HCI, it is not easy to make computer systems easy to use by people with different levels of literacy, particularly in healthcare. Accessibility is not only technical conformance but also cultural suitability, linguistic clarity, and usability. Since e-health will be playing an ever more public face within public services, most prominently within the developing world, technology takeup that has an impact starts with designing for cultural sensitivity to local needs and limitations.

Several studies have explored the adoption of technology in illiterate or semi-literate users, and different UI design methodologies have been posited as a consequence. Medhi et al., [4] conducted a comprehensive study of UI design without the use of text for Indian slum workers and determined that graphical icons, audio cues, and simplified navigation were more effective than their text-based counterparts. Participants always opted for audio-visual equivalents and semi-abstracted photographs for self-examination navigation without overt literacy.

Similar research was done by Khan et al., [9] for Pakistani job seekers who did not know how to read. They put a lot of effort into fitting the culturally relevant elements in the design, but they understood that each country's language made it hard to generalize the design. Huenerfauth [6] also advocated speech recognition, touch input, and non-linguistic graphics for illiterate users over multi-modal, intuitive UI designs limiting text input. Ahmed et al., [15] created a smartphone app for low-literate citizens in Bangladesh, demonstrating the success of participatory design for marginalized groups. Despite these innovations, very few studies in Bangladesh specifically address UI design considering literacy and accessibility. The majority of applications are focused on usability but neglect educational and cultural diversity. According to Mtebe et al., [21], simpler UIs sometimes sacrifice security if not balanced equally.

Cultural convenience is also involved. Videoconferencing has proved to be useful in rural Canada to enhance access to medical care while maintaining patients comfortable with traditional settings, said Agnelli, [39]. This shows that availability must be aligned with user convenience and social culture. Our design takes the lessons from those studies and focuses on being inclusive from the beginning. Specialists gathered information by talking to patients from government and private hospitals in Bangladesh, who were all from different levels of society and education. Because of this, our user interface was made visual, icon-based, and offered voice support to help people with both high and low levels of literacy, drawing from the work of Medhi et al., and Huenerfauth [9][15].

It also enables real-time interaction, such as video consultations, lowering the psychological barrier of hospital visits and agreeing with Agnelli's proposition [39]. For economically disadvantaged consumers, we offer reduced-cost online consultation options, supporting Akhter et al.'s argument [15]. In avoiding usability-security trade-off, our application enables consent-based exchange and tiered access without affecting the simple, user-friendly interface. Continuous usability testing ensures features remain accessible.

Overall, our system bridges the divide between technological design and social contexts in the world, offering a digitally accessible, flexible, and inclusive healthcare platform. Role-based access control (RBAC) is among the foremost security models in health systems, whereby users only access the data and functionality that pertains to their role. In Dinesh et al., [24], a system is presented where the backend database controls valuable information regarding patients, doctors, pharmacies, and administrative staff. People who use the system are identified by their own unique usernames and passwords. Users are required to sign up beforehand to get access to the portal. When a user logs in, the system changes its way of interacting based on their level of access. Doctors are able to view patients' details, fix appointments for them, and send them messages, while patients can book appointments and communicate using the messaging system. The stringent role differentiation provides data security and sufficient user interaction.

Likewise, Harris et al.'s [31] description of PROACT 2.0 emphasizes role-specific functionality and clearly states that there is no provision for emergency calls. Instead, patients are directly instructed to contact country-specific emergency numbers if an urgent need arises. This feature is highlighted on the initial login and within the manual. Our Cancer app has three types of users, each with different access levels. The important data is not accessible to anyone except authorized individuals. We have taken care to ensure that no one's privacy is compromised.

2.4 Severity-Based Triage Systems

Severity triage systems are also a necessity in healthcare systems so that cases can be prioritized based on how urgent the condition of the patient is. Through the provision of labeling and sorting of medical requests, the systems allow the serious cases to receive attention instantly, while not-so-severe cases are handled in due course. A triage system can be utilized in healthcare applications to better enhance response time, workflow, and patient safety.

In current systems, like the one researched by Harris et al.,[31] a triage system based on severity has been included in the design to avoid misdirection of emergent cases. For example, emergent cases are labeled with clear alerts, which guide patients to the respective emergency pathways. Harris et al. refer to the need for explicit identification of non-urgent cases with a clear message indicating that the application is not appropriate for emergency communication, and consequently reducing confusion among users.

Expanding on this concept, our proposed cancer care app incorporates an emergency tagging functionality to support the triage system. The application will implement red alerts for emergency case tagging, which require immediate medical intervention. For instance, once the patient experiences symptoms like sudden pain or signs of a possible life-threatening problem, the system will automatically alert the medical practitioner and flag the problem as an emergency, thereby handling it with urgency. In doing so, it also facilitates easy movement of non-emergency requests and consultations, promoting neat and effective administration of healthcare services. With the incorporation of this triage system, our application is designed to provide an improved response time and maximize patient care.

Chapter 3

Interview process and data collection

3.1 Overview of Interview Process

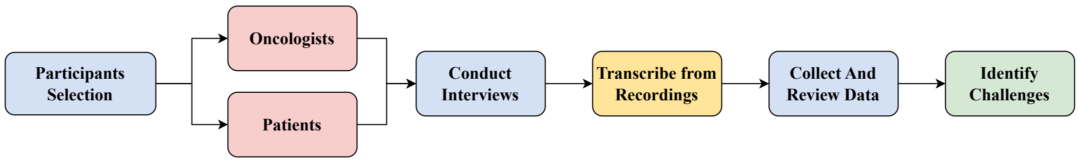

Figure 3.1: Overview of Interview Process

Fig 3.1 illustrates the workflow of the interview process which begins with the selection of participants, with a particular emphasis on patients and oncologists who could provide useful insights. 32 participants participated in the interview process. After gathering 12 oncologists' experiences, perspective, and challenges, and 20 patients who describe their personal experiences with cancer treatment. Once the groups were defined, interviews were conducted using a mix of open ended and closed ended structured questions to gather rich and qualitative data. Each interview was audio recorded with a recorded version transcribed to ensure accuracy and completeness. After transcription each and the data was collected and thoroughly analyzed to detect patterns and recurring themes. In the end the thematic analysis study was able to identify the interview data, the challenges we faced during interviews with patients and oncologists and they provided the basis for informed recommendations and the design of more user-centric cancer care solutions.

Interviews are a vital part of qualitative research, especially when investigating topics that are complex and personal, like cancer treatment. To gain more knowledge of the current state of cancer care and to identify the methods to enhance patient outcomes. The interview procedure was designed to offer an in-depth understanding of treatment and experience of cancer care in both public and private hospital settings by analyzing the perspectives of both healthcare professionals and patients. The approach of the interview is chosen for its ability to offer context-specific, personal, and detailed information, which is essential for a subject as complex and sensitive as cancer care. Unlike surveys or data Interviews, which offer personal, detailed, and comprehensive insights into the lived experiences of individuals.

Cancer care is not just dealing with clinical procedures for medical data; it also includes the journey of patients, their interactions with the healthcare system, and the strategies applied by physicians and nurses to address emotional and resource related obstacles. Interviews help to gather human experiences which are important for the identification of genuine issues and the development of practical solutions. Quantitative data like treatment success rates or hospital capacity, indicate development but it fails to clarify the reasons for this development. These reasons are revealed by the interviews. Also interview responses can serve as a source of inspiration for practical suggestions. Patients may disclose their emotional and financial hardships while physicians propose structural improvements. These responses contribute to the development of user-centered strategies which are a fundamental principle of HCI(Human-Computer Interaction).

In both public and private hospitals interviews are being conducted. A broader range of experiences was intended to be addressed by comparing both categories of hospitals. Private hospitals provide more personalized care at a higher cost, while public hospitals frequently serve a large population with limited resources. This comparative perspective was crucial in understanding the systematic obstacles and differences in service delivery that influence patient outcomes. Among the participants were cancer patients, patients' relatives, and oncologists who are involved in cancer care. Patients in various stages of treatment, including those who are in a state of recovery and who newly discover the cancer, were interviewed to capture a variety of perspectives. All participants were chosen based on their willingness to participate and their relevance to the research topic. Both open-ended and closed ended questions were included into the interview format. Healthcare professionals were questioned regarding the obstacles they face in patient management, access to resources, treatment protocols, and the provision of care. Furthermore, they were asked to offer their opinions on potential modifications that could be implemented to improve the results. Patients were asked questions that were intended to record their contention with treatment, lived experiences, support systems, and any changes. As a result of the study's structure, participants were able to share their personal experiences and collect measurable data, which enhanced the findings.

Before the interviews were conducted, each participant received an introduction that explained the goal of the investigation, the intended use of data, and the significance of voluntary, informed consent. Patients were provided with a pleasant environment that recognized the emotional impact of their health conditions. The majority of interviews were conducted in Bengali, and the interviews lasted between 40 and 50 minutes, depending on the participants preference. Also, for interviews, the clinical environment and service delivery in both public and private facilities were explained through observations during hospital visits. In public hospitals there were high patient loads, extended waiting periods, and inadequate staffing were frequently encountered. In addition, private hospitals frequently possessed superior facilities, reduced waiting times, and more personalized services. However, affordability was a considerable burden for numerous patients.

The data obtained through interviews were thoroughly reviewed and transcribed. For the sake of consistency, responses in Bengali were translated into English. Thematic analysis was employed to identify patterns and essential themes in the interviews. The need for better follow-up care is commonly discussed, as is financial hardship, communication gaps between patients and providers, emotional and psychological support deficiencies, and delay in diagnosis. Frequently, healthcare providers identified obstacles such as a lack of specialized support, resource constraints, and patient congestion. Throughout the procedure, ethical considerations were rigorously observed. The appropriate ethical review board approved this study. Data were securely preserved to safeguard privacy, and participants' identities were granted the right to withdraw at any time without providing a reason, and no financial rewards were provided. Some limitations were evident, despite the huge amount of data. Not all healthcare professionals were available for in-depth interviews, primarily in public hospitals, due to time constraints and workload pressures. In certain instances, the depth of patient responses may have been restricted by emotional health conditions. In addition, the results of this qualitative study do not apply to the entire population. However, they provide a valuable examination of personal and professional perspectives.

3.2 Challenges during Interviews

Interviews were important for obtaining personal perspectives on cancer care. The quality and consistency of the responses were strongly influenced by the participant's availability, emotional state, and technological familiarity. These challenges not only impacted data collection but also revealed the broader infrastructure and communication flaws within the healthcare system. The obstacles experienced during the interview phase of the study are narrated below.

3.2.1 Difference between Public and Private Hospitals

Equal representation of public and private hospitals in the survey and interview process was a major obstacle. Due to concerns about patient comfort and privacy, private hospitals frequently set limitations on interactions between patients and doctors. In some cases, patients were uncomfortable giving interviews in a private hospital. Also, it was difficult to get interviews with oncologists and with other medical specialists. Finding interested consents got more challenging after one or two interviews because many doctors had busy schedules.

3.2.2 Challenges in Patient Interviews at Public Hospitals

Conducting interviews with patients in public hospitals came with its challenges. In public hospitals, there were middle-class and lower-class people present. Confusion was frequently expressed while explaining the goal and operation of the interview process, especially when digital apps were involved. Many patients who engaged in interviews were unfamiliar with smartphones or mobile health apps, which caused misunderstandings. This lack of technology made it difficult to gather thorough patient experiences and feedback.

3.2.3 Reluctance of Patients and Guardians to Participate

During interviews, many patients refused to be questioned frequently because they were too tired, experiencing mental discomfort, or were unfamiliar with the importance of the study. When patients were unable to describe their experiences, family members were contacted. Some family members answer instead of the patients. Few guardians also lacked an in-depth understanding of the patient's treatment plan, which resulted in information being lacking. The depth of patient-centered data was constrained by this hesitation and the absence of thorough answers.

Chapter 4

Methodology

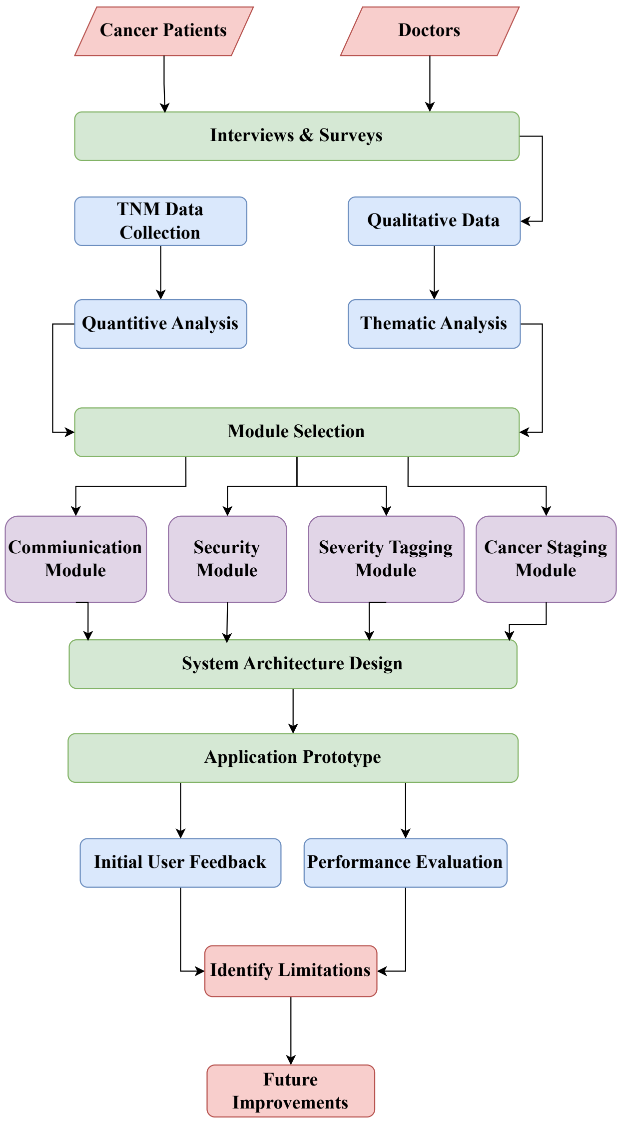

Figure 4.1: Methodological Workflow Of Our Study

The project workflow in Fig 4.1 uses a variety of paths. The workflow begins by capturing opinions about cancer from patients and cancer specialists via interviews and surveys. Next, gathering TNM data and employing the methods of both qualitative and quantitative data analysis. The data analysis leads us to define which modules include communication, security, severity tagging, and cancer-staging; each module selected guided the design of our system's architecture. From here, we explored ways to prototype the application initially with the insight feedback from users (cancer patients) and assess its performance, recognizing the limitation/constraint was significant, so we identified our next set of improvements for this system. The project is an iterative cycle we anticipated while developing the project plan to use real data for improvement and our systems end-users' needs.

This study implemented a qualitative research design to examine the obstacles associated with the administration of cancer care and to investigate possible ways to enhance the patient experience through the implementation of a focused on people for digital approach. A sample of 32 participants, including cancer patients and healthcare professionals, was selected from public and private hospitals in Bangladesh. In order to gather comprehensive information regarding diagnosis, treatment, and healthcare access, informal interviews were implemented. Braun and Clarke's six-step thematic analysis framework was applied to analyze the collected data, enabling the identification of emergent themes from participant statements. It was able to identify repeating concerns, including financial burden, communication gaps, lack of emergency care, and willingness to accept digital health tools, as a result of this inductive approach. A patient- centric mHealth platform was designed and developed in direct response to these findings. Four important modules compose the system architecture: a security module that employs token-based authentication, a severity tagging system for deciding on patients' requirements like emergencies, a TNM-based cancer staging module, and real-time doctor-patient communication through WebRTC. For the mobile interface Flutter is utilised, Django REST Framework is implemented for backend APIs, and PostgreSQL is implemented for structured data storage. Therefore, the development of a contextually grounded accessible digital healthcare system that has been developed specifically for cancer patients in Bangladesh became possible by the combination of qualitative analysis and HCI-informed technical design.

4.1 Participants

Our study involved a total of 32 participants, including healthcare professionals and cancer patients. We selected these participants for our study because they offer valuable perspectives into the standard and method delivery of cancer care. The selection of participants were purposive sampling for qualitative research, where we can gather in depth information from individuals who have direct experience with cancer. The cancer patients were selected determined by their diagnosis and treatment history. All patients had been diagnosed with cancer and were in the process of completing or were currently enduring active treatment at the time of the study. They represented a variety of cancer stages, like early stage, advanced stage, and remission. In order to accurately represent the disparities in quality, affordability, and accessibility of treatment, patients were selected from both public and private hospitals.The group of oncologists, general physicians, and administrative staff who are directly involved in the diagnosis, treatment, and patient support of cancer. To facilitate the comparison of practices and challenges among various types of healthcare institutions, these specialists were chosen from both public and private hospitals.The perspectives of each professional were firmly rooted in real world practices. They had a minimum of one year of experience in oncology or cancer-related healthcare.The criteria participants were followed like willingness to voluntarily participate in the survey, and ability to give informed consent. And for healthcare providers, they have to minimum of one year of relevant professional experience, for patients who are currently receiving or previously received cancer treatment within in the last 3 years. Therefore, participants were conducted after informed consent was given and participants were approached during hospital visits. The data obtained was enhanced by the diversity of roles, institutions, and personal backgrounds, which supported a thorough examination of patient outcomes and care strategies in various healthcare settings.

4.2 Qualitative Data Analysis

Qualitative data is a crucial part of any HCI research work. According to Denzin & Lincoln, qualitative data consist of non-numerical information that is used to encapsulate complex experiences, emotions regarding the research, and other contextual information [19]. In this study, qualitative data authorizes a more in-depth understanding of the mindset of cancer patients, their caregivers, and healthcare professionals. To develop a user-centric, culturally adequate mobile application, these insights were vital. Because they address not only the logistical challenges but also the psychological and communication gaps that exist in cancer care.

For our study, the qualitative data were collected through two parallel streams. First were the open-ended responses from the cancer patients or their caregivers, most of whom are from urban or peri-urban regions of Bangladesh. And second were interviews with practicing oncologists and medical professionals in urban Bangladeshi healthcare settings. The patient and their caregivers' responses provided insights into the everyday mental and physical struggles that they face during the diagnosis. The doctors' responses helped enrich our research analysis by providing systematic perspectives. The doctors' inputs emphasized the fragmented nature of existing record-keeping, the need for a real-time monitoring system, and a patient tagging system based on emergency, especially for patients in palliative care. This perspective was crucial for the triangulation and validation of the user-reported concerns, which is necessary for ensuring a more robust and practical design framework for the application. This method of open-ended data collection correlates with the patient-centered approach recommended in digital healthcare design literature, as emphasized by Ha and Longnecker [7] and Khan et al. [32]. Collecting these narratives allows researchers to move beyond the surface-level metrics and understand the underlying needs and behaviour patterns needed for cancer care, specifically in settings where resources might be constrained.

4.2.1 Analytical Framework

We performed thematic analysis across both qualitative data, which include patients' or their caregivers' responses, and the doctor interviews. Triangulation of the result was made possible by the oncologists' inclusion and insights that shed light on some evident issues. As Braun and Clarke [3] described, thematic analysis was developed to analyze open-ended responses in research work. This is a flexible yet meticulous framework that is used for identifying, analyzing, and obtaining themes (patterns) within a qualitative dataset. This is a six-step process that includes familiarity with the data, generating initial codes, searching for applicable themes, reviewing the themes, defining and naming the themes, and finally, constructing the thematic narrative [3]. This is a manual approach that allows researchers to come up with a profound and contextually grounded interpretation of the participants' responses. The inductive method was used to generate the codes for this analysis. Which means. The themes were not imposed before the interviews; they were independently coded and refined from the interviews. Additionally, the insights for this thematic analysis were triangulated with findings on Khan et al.'s mHealth [32], Mahmoud & Abozariba's WebRTC-based communication modules [47], and Medhi et al.'s culturally adapted human-computer interaction [4]. This helped ensure that the interpretation of the responses was grounded in observed data and also informed by the latest advancements in cancer care technologies.

4.2.2 Thematic Analysis

We followed Braun and Clarke's six-phase framework for this thematic analysis: (1) getting familiar with the data, (2) identifying primary codes, (3 Identifying themes, (4) reviewing themes, (5) labeling and defining the identified themes, and (6) final report [3]. We used an inductive approach that allows themes to emerge directly from participant narratives without pre-established coding categories. To maintain confidentiality and ensure transparency, direct quotes have been cited using anonymized participant IDs such as (P2, male, 35) for patients and (D3, male) for doctors.

The interview explored patients' experience with the cancer diagnosis, how they managed and tracked their symptoms, whether they have a clear understanding of the treatment procedure, if they can communicate with doctors properly, how they cope mentally, and any ideas they have for improving their diagnosis. The doctors were asked about the communication issues with the patients, what they expect from a digital platform, and which features would they find useful in a clinical setting.

A clear pattern was visible around the financial burden of the patients. Most of them expressed that the treatment cost, including the diagnostics and test reports, was overwhelming for them. One patient added, discounted hospital service would help (P3, male, 28). A lot of patients reported that they missed medication doses or forgot their appointments. This was evident mainly in older patients. This indicated a lack of a structured medication reminder tool. Answers like "I forget whether I've taken my medicine" (P4, male, 60) and "Appointment time would be nice to have" (P3, male, 28) highlighted the need for built-in medication reminders. One interesting finding was that, despite most patients not having any previous exposure to mHealth applications, most of them were willing to use one, given that it would be easy to use. Responses like “Yes, it will make life easier” (P4, male, 60) and “Yes, for better treatment” (P0, male, 27) were common. Almost all of the patients relied heavily on their family support, keeping them mentally strong. Only a few mentioned getting institutional help. When asked what kept them strong during this diagnosis, they replied, “Family support.” (P0, male, 27) and “Spending time with my family.” (P4, male, 60). On the other hand, the majority of the patient showed confusion regarding their diagnosis and treatment procedure. They also expressed that they didn’t properly understand the medical explanations. Most of them depended entirely on the doctors for any medical clarity. Remarks such as “Nothing specific comes to mind, but I would like proper explanations” (P4, male, 60) illustrate this issue.

On the systematic side, patients expressed that the transportation cost and time, as well as the waiting time in the hospital, were major issues. Multiple people spoke of delays in getting reports and having to wait a full day for a short consultation. “Reports come late, have to wait in line.” (P1, male, 35) and “It takes a whole day to just consult for 10 minutes.” (P2, male, 50) are some of the answers that illustrate the situation. The communication challenges were faced by both the doctors and the patients. Patients often mentioned not being able to describe their symptoms, feeling anxious, and forgetting to bring necessary reports during consultations. The doctors emphasized these problems, too. “Patients forget their documents or can’t explain symptoms properly.” (D0, female) and “They forget reports and I don’t get full history.” (D3, male).

One of the major themes was the lack of immediate care during medical emergencies. Patients often endured pain without any instant help. One patient shared, I had pain at night, but I waited till morning.” (P5, male, 50). Meanwhile, the doctors stressed the need to prioritize urgent cases first and have an automated tagging and triage system. Also features like messaging, voice, and video chat, and document upload. Finally, the doctors also indicated their fee expectations that ranged from BDT 400-700. This feedback supports the inclusion of a flexible payment structure in the proposed digital platform.

4.2.3 Synthesis of Findings

The interview data from both the patients and doctors highlighted a lot of ongoing challenges for cancer care in Bangladesh. Patients often face a combination of financial strain, long hospital queues, excessive transportation costs, and time, and a lack of clear understanding regarding their diagnosis. Many do not use any tools to track their symptoms or log their medications and heavily rely on their family members for these tasks. Also, most patients had no way to contact a doctor directly during an emergency. Even though there has been very limited exposure to digital health applications, most patients showed willingness to use such tools if they’re made accessible and easy to use.

The doctors echoed these concerns. They also reported facing difficulties while communicating with the patients. A lot of times, the documents would be missing, or the patients were unable to express their symptoms or difficulties properly. They acknowledged the need for a structured digital system that can manage urgent cases, share documents securely, and streamline patient consultations. The doctors were open to engaging in remote consultations if a fair compensation model were integrated.

The insights from both parties reinforce the necessity for a user-friendly, affordable mHealth platform. The application design should reduce patients' stress and support symptom tracking and triage, enabling real-time communication.

Theme	**Key Insights**	**Design Implications**
Financial Burden	Treatment and transport costs deter continued care	Financial navigation tools, subsidies, virtual consults
Forgetting Timely Medication and Appointments	Missed doses and appointments affect patient outcomes	Medication reminders, tracking dashboard
Willingness to Use Digital Platforms	Patients are open to tech if provided proper assistance	Simplified UX, Bangla onboarding
Emotional Support	Patience relies heavily on family for resilience	The family should be able to navigate the app for the patient
Diagnostic Uncertainty	Many patients don't understand their diagnosis	TNM for staging, test summaries
Healthcare Access Limitations	Long travel time and waiting queue in the hospital	Online consultation and queue navigation
Communication Gaps	Both the patient and the doctor struggle to communicate and obtain the full history	Structured symptom tracking, persistent messaging
Emergency Inaccessibility	No real-time emergency doctor access	Priority-based patient tagging system for emergency cases
Clinician Triage Challenges	Doctors need urgency filters and structured interactions	Symptom-based triage, chat/video, doc sharing

Table 4.1: Themes, Insights, and Design Implications from Qualitative Research

Table 4.1 synthesizes key patient-identified themes from interviews and aligns them with actionable design implications for developing a user-centered cancer care mobile application.

4.3 System Architecture and Modules

The core of the system includes four key modules that support secure and real-time interactions between doctors and patients. The WebRTC Module is responsible for Peer-to-Peer Communication, the Security Module for Token-Based Authentication, the Patient Severity Tagging Module for efficiently grouping up patient requests based on their severity level, and the Cancer Staging module for calculating the stage of the cancer using the TNM dataset. These modules are integrated into the main application to address critical challenges in remote cancer care. Flutter is used for developing mobile applications for its cross-platform capabilities. Node.js and Socket.io is used for developing the signaling server using WebSockets. Django REST Framework is used for building the security module and the main backend server of the application. PostgreSQL is used as the database server for the whole application. An overall system architecture diagram is illustrated in Figure 4.2

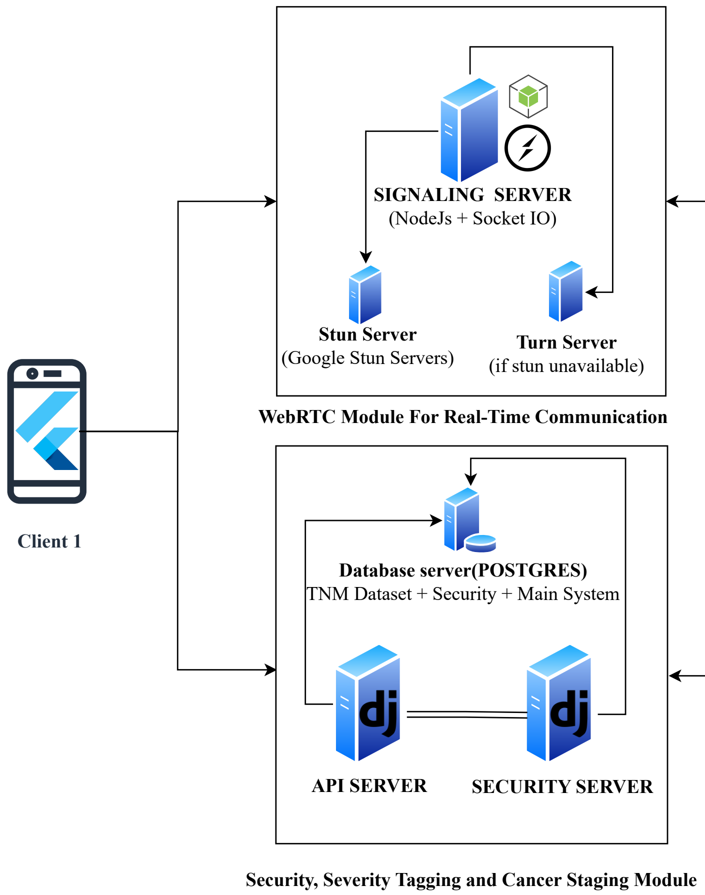

Figure 4.2: Overall System Architecture

4.3.1 WebRTC Module for Peer-to-Peer Communication

To facilitate real-time communication between doctors and patients, we employed WebRTC (Web Real-Time Communication), an open-source technology that enables peer-to-peer (P2P) audio and video communication directly between two devices, proven by Google [34]. In the view of Loreto et al., WebRTC is particularly suited for telemedicine applications due to its low latency, secure, and reliable connection capabilities, which are essential for high-quality doctor-patient interactions. The overall system architecture that supports the WebRTC implementation is illustrated in Figure 4.3

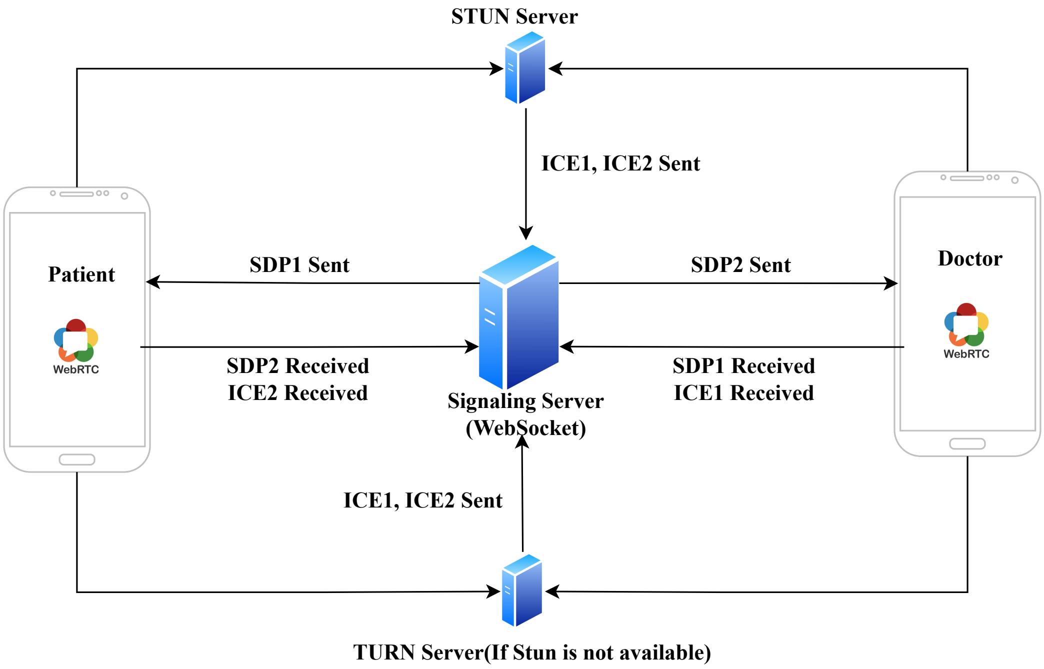

Figure 4.3: WebRTC System Flow

Figure 4.3 depicts the flow of communication between the patient, doctor, signaling server, and auxiliary servers like STUN and TURN. The WebRTC system consists of three key components: Signaling Server, STUN (Session Traversal Utilities for NAT) Server, and TURN (Traversal Using Relays around NAT) Server. These components work together to establish a direct P2P connection between the doctor and patient, allowing real-time communication without the need for central servers to handle the media stream stated by Baugher et al., [1].

Signaling Server

The Signaling Server is responsible for coordinating the connection between the doctor and patient by exchanging Session Description Protocol (SDP) messages and ICE (Interactive Connectivity Establishment) candidates. As stated by Rosenberg et al., SDP contains essential information about the media format, network parameters, and codecs, while ICE candidates help the two devices discover the best network path for communication [5]. In our system, when the patient initiates a session, an SDP offer (SDP1) is sent from the patient's device to the signaling server, which then forwards it to the doctor. The doctor responds with an SDP answer (SDP2) through the same server, completing the session negotiation. Once the SDP exchange is completed, ICE candidates are exchanged to determine the optimal network route for the media stream (see Figure 4.3 and Figure 4.4).

STUN and TURN Servers

To overcome network restrictions such as NAT (Network Address Translation) and firewalls, the system integrates both STUN and TURN servers. The STUN server is used to help the doctor and patient devices discover their public-facing IP addresses,

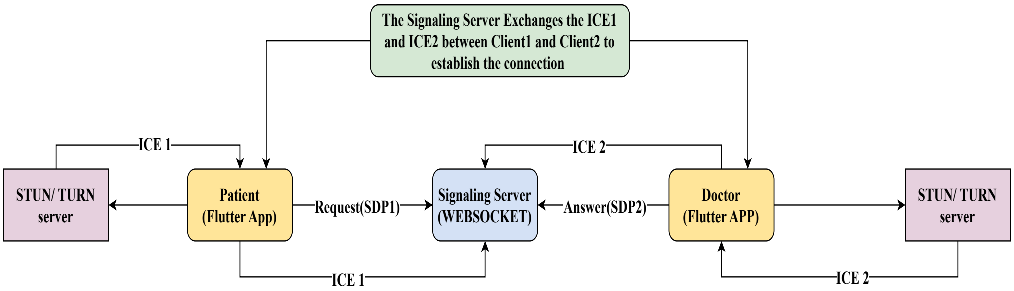

Figure 4.4: Communication flow of Signaling, STUN and TURN

allowing them to establish a direct P2P connection. According to Mahy et al., If the STUN server is unable to establish this connection due to strict network policies or firewall constraints, the TURN server acts as a relay to ensure that the media stream is still successfully routed between the two parties [8] (Figure 4.4). The following STUN servers were used for our application based on their availability:

- stun.l.google.com with address 74.125.192.127
- stun1.l.google.com with address 172.217.192.127
- stun2.l.google.com with address 142.250.15.127
- stun3.l.google.com with address 108.177.15.127
- stun4.l.google.com with address 108.177.119.127

Peer-to-Peer Media Streaming

Once the SDP and ICE candidates have been exchanged, a secure P2P connection is established between the doctor and the patient. The audio and video streams flow directly between the two devices, bypassing any intermediary servers. This direct connection reduces latency, ensuring smooth real-time communication, which is crucial in telemedicine scenarios. In cases where a direct connection cannot be achieved (e.g., due to restrictive NATs or firewalls), the media stream is relayed through the TURN server, which ensures reliable communication without compromising on security or performance said Ford, Srisuresh, & Kegel et al.,[2] (as shown in Figure 4.3 and Figure 4.4).

Security and Encryption

As reported by Baugher et al., WebRTC incorporates DTLS (Datagram Transport Layer Security) for encrypting the signaling data exchanged between the devices, and SRTP (Secure Real-time Transport Protocol) for encrypting the media stream[1]. These built-in encryption protocols ensure that all communication between the doctor and patient is secure and compliant with privacy requirements.

For this study, WebRTC was used to establish real-time video and audio communication between doctors and patients during remote consultation sessions. The P2P nature of the WebRTC architecture ensured that the media streams were transmitted with minimal latency, providing a smooth and interactive experience for both parties. The system was designed to be resilient in various network environments, utilizing STUN for direct connections and TURN as a fallback option in cases where NAT traversal or firewall restrictions made direct P2P connections difficult. Additionally, local storage on both the doctor's and patient's devices was utilized for caching session data, helping to maintain session continuity even in the event of temporary network disruptions (Figure 4.3). Participants reported positive feedback about the communication experience, with no issues regarding connection stability or quality. The built-in security features of WebRTC also ensured that all interactions remained private and secure, making it an ideal choice for the telemedicine context used in this study.

Integration with mobile application:

The doctor and patient both will be able to join the video call during their designated appointment time from their respective dashboard. In both doctors' and patients' dashboards, they can access the individual appointment details and join the video call using the join video call button(Figure 4.5)

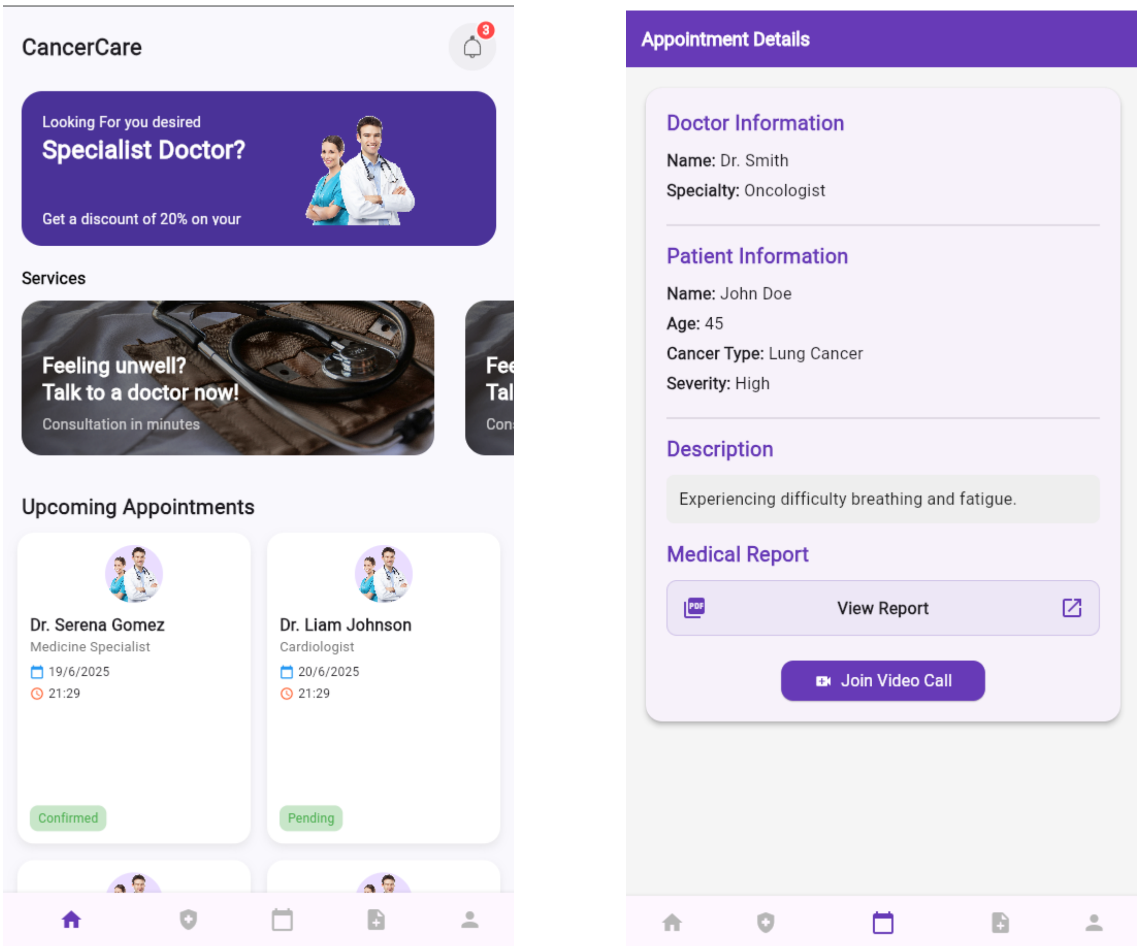

Figure 4.5: Main Dashboard Page(Patient) Appointment Details

If someone joins the video call, the other person (doctor or patient) will get notified to join the video call. Once both doctor and patient join their respective video call session, they will be able to communicate using a video call interface (Figure 4.6). The quality of the video and audio of the video call depends on the network connectivity of both users. Also, a maximum of two users can join a meeting(doctor & patient), and their respective user IDs get checked in the backend before they are allowed to connect to the session.

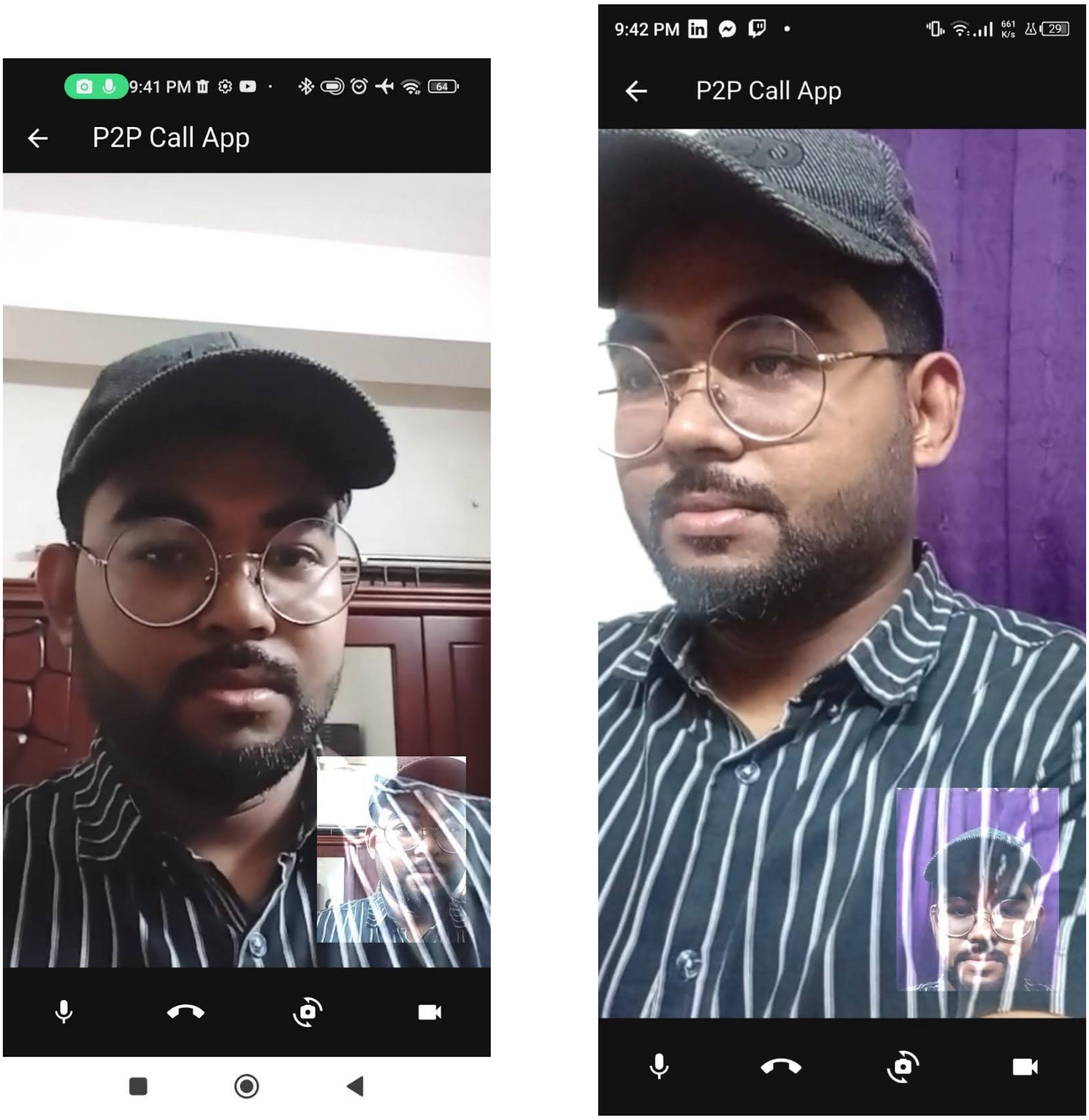

Figure 4.6: Live video call from doctor side(left) patient side(right)

4.3.2 Security Module for Token-Based Authentication

Based on the findings of Jones, Bradley, Sakimura et al., to ensure secure access and authorization within our system, we have implemented a token-based authentication mechanism using Django Rest Framework (DRF) integrated with JSON Web Tokens (JWT) [13]. This security architecture provides stateless authentication, which is crucial for scalable web applications, particularly those involving sensitive data, such as in our telemedicine platform. JWT allows us to authenticate users without needing to store session data on the server side, thereby reducing the complexity of managing session states while maintaining security. However, as JWT tokens are stateless and valid until they expire, it is necessary to employ a blacklisting mechanism to revoke tokens if required, such as in cases of user logout or account compromise. The security module leverages the DRF JWT Blacklist functionality to manage token revocation efficiently. The Entity-Relationship (ER) diagram of the security module is presented in Figure 4.7.

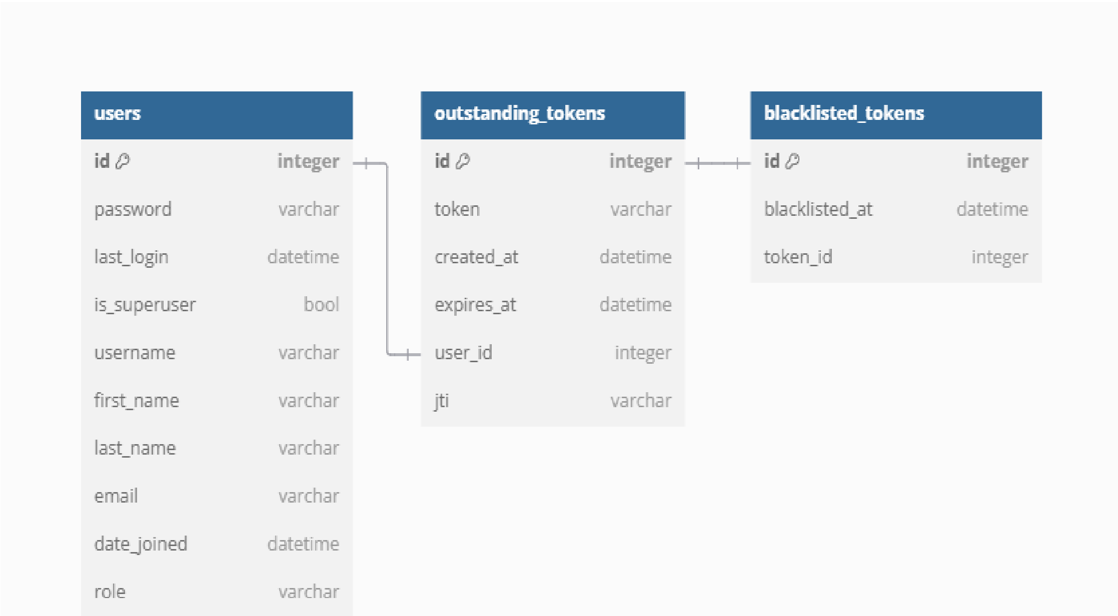

Figure 4.7: Entity Relationship Diagram for Security Module

illustrating the interactions between users, outstanding tokens, and blacklisted tokens in the system.

Token Authentication Workflow

The system generates a JWT token for users upon successful login or registration, which contains encoded information about the user (user ID and role) and an expiration timestamp. This token is then passed back to the client, which stores it for subsequent API requests. Each time the client makes an authenticated request, the token is included in the HTTP headers, and the system verifies it before granting access to protected resources.

Outstanding Tokens and Blacklisting

In the security module, valid tokens are tracked using the Outstanding Tokens table (Figure 4.4). Each entry in this table records the following attributes:

- **token**: The actual JWT token string.
- **created_at**: The timestamp when the token was issued.
- **expires_at**: The expiration time of the token.

- **user_id**: The foreign key linking the token to the specific user in the Users table.
- **jti (JWT ID)**: A unique identifier for each token, which ensures that each token can be uniquely identified and managed within the system.

When a user logs out or a token needs to be revoked for security reasons (e.g., token compromise or privilege changes), the token is added to the Blacklisted Tokens table. This table contains:

- **token_id**: The reference to the associated outstanding token that has been invalidated.
- **blacklisted_at**: The timestamp indicating when the token was blacklisted.

Upon receiving a new request, the system checks both the Outstanding Tokens and Blacklisted Tokens tables to determine the validity of the token. If the token is present in the Blacklisted Tokens table, access is denied, and the user is required to re-authenticate.

Security Features

1. **Stateless Authentication**: The use of JWT ensures that the server is not required to store session data. Each request from the client carries the token, which is verified and decoded to authenticate the user.
2. **Token Blacklisting**: Tokens can be manually blacklisted at any time to ensure that revoked tokens are no longer valid, protecting the system from unauthorized access.
3. **Expiration Control**: Tokens have a pre-defined expiration time, limiting the duration of their validity and reducing the risk of long-term misuse.
4. **Role-Based Access Control (RBAC)**: The token payload includes the user's role, which allows the system to enforce fine-grained access controls based on the user's privileges.

This security module is employed to manage user authentication and access to protected endpoints within the system. Patients and doctors are assigned specific roles that determine their level of access, and all communication between the client and server is protected using token-based authentication. The blacklisting functional it ensures that token revocation can be handled seamlessly, which is particularly important for safeguarding sensitive health data and maintaining user trust.

User Authentication from Mobile Application

From the mobile application developed using Flutter, patients can register for a new patient account and sign in using their credentials (illustrated in Figure 4.8).

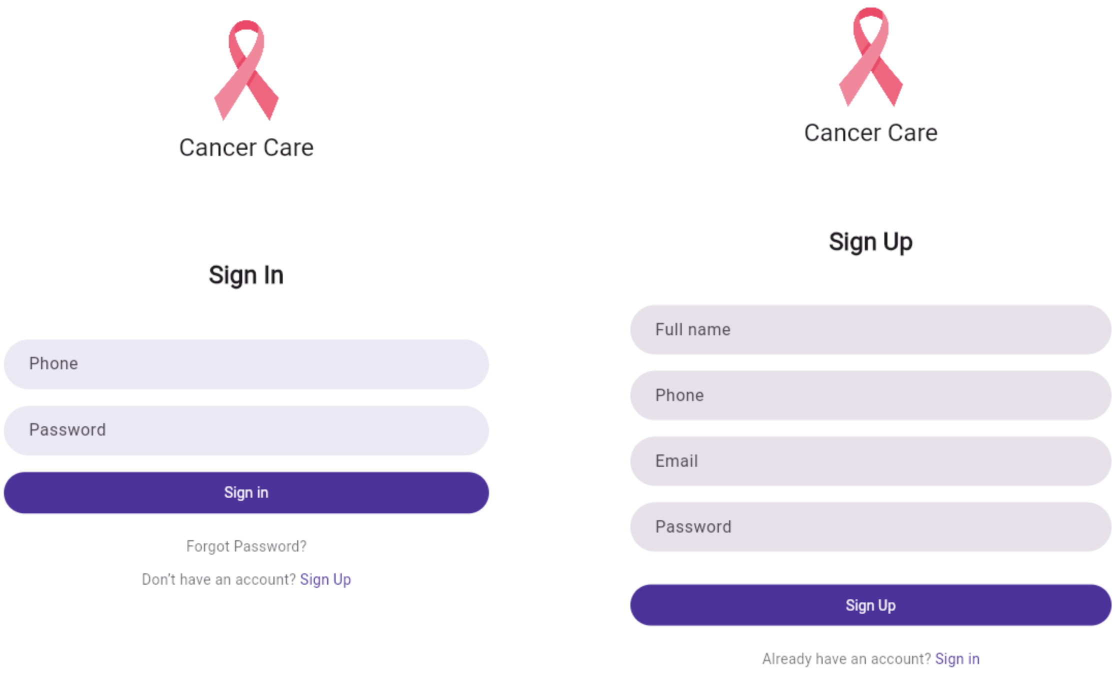

Figure 4.8: User sign-in and sign-up from mobile application

The backend of both of these features is handled by the security module. Doctors are required to request a doctors account from the admin by providing all information that will verify their status as a doctor. So, currently, the doctors can't directly register using the user interface of the mobile application. Once the doctor is verified, the admin will manually add him in the list of verified doctors in the backend.

4.3.3 Severity Tagging System for Patient Triage

For better categorization and grouping of patient appointment requests, we have implemented a severity tagging system based on a severity score. This module is designed to enable doctors to prioritize patients with higher severity levels, allowing them to schedule appointments as soon as possible. From the patient's side, the system is simple enough for them to schedule appointments with a reasonable waiting period based on their severity. An overview of the module is illustrated in Figure 4.9

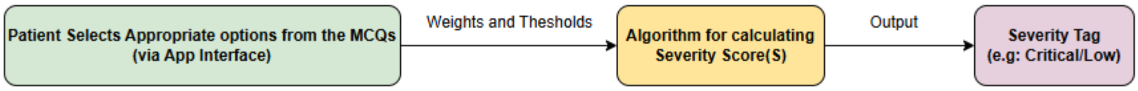

Figure 4.9: Overview of Severity Tagging Module

Algorithm for Calculating Severity Score(S):

As shown in equation (4.1), the triage module assigns each patient a severity score (S) based on weighted responses to a series of multiple-choice questions (MCQs). Let each MCQ response i have a fixed weight Wi, and let Ai be an indicator (1 if the patient selects that response, 0 otherwise). The total severity score is computed as:

$$S = \sum_i W_i A_i, \quad A_i \in \{0, 1\} \tag{4.1}$$

For example, if a patient selects three responses with weights

$$\mathrm{W}_1 = 2, \quad W_3 = 4, \quad W_5 = 1$$

We then map S to a severity category according to predefined thresholds:

- **Low (0–3)**: No urgent concerns.
- **Moderate (4–6)**: Mild to moderate concerns.
- **High (7–9)**: Significant concerns requiring prompt attention.
- **Critical (≥10)**: Highest urgency.

(These thresholds are illustrative; exact cut-offs and weights are tuned to match clinical priorities.)

Some answers (e.g., symptoms or findings deemed immediately dangerous) trigger red-flag overrides. If any such red-flag response is present, the system automatically assigns the "Critical" category, regardless of the computed S. This mimics real-world triage protocols where certain findings demand instant escalation.

Similarities with Established Clinical Triage Tools:

As stated by Tipton K, et al, our scoring approach parallels established triage tools. For example, the Emergency Severity Index (ESI) is a five-level algorithm (ESI 1–5) that categorizes patients by acuity based on vital signs and clinical criteria [38]. Like ESI's framework (which assigns "Immediate" for life-threatening cases, "Emergency," etc.), our system uses weighted criteria to stratify urgency. Similarly, the NEWS2 (National Early Warning Score 2) in hospital settings aggregates six physiological parameters (respiratory rate, oxygen saturation, blood pressure, pulse, consciousness, temperature) into a total score reported by Myrstad, M. et al., [27]. NEWS2 has defined trigger thresholds (e.g. scores of 5–6 prompt urgent review, 7 emergency response). Similarly, our MCQ weights function analogously: deviations (answers) contribute to a total score, and surpassing a threshold yields a higher priority level. In both cases, the sum-of-weights paradigm enhances objectivity and reproducibility in triage decisions. Moreover, integrating rule-based "red flags" aligns with Clinical Decision Support (CDS) design principles. Contemporary CDSS literature notes that combining algorithmic logic with explicit rules can improve performance and interpretability. For instance, Berge et al., [35] report that a hybrid ML/rule-based CDSS "benefits system performance, efficiency, and interpretability". By hard-coding critical-symptom overrides (the red-flag logic), our system ensures that obvious emergencies receive the highest priority, much as ESI immediately flags certain signs as ESI level 1.

Overall, the severity tagging module justifies its design by analogy to these clinical tools: it uses a transparent, additive scoring function with clear thresholds (as in NEWS2) and immediate override rules (as in ESI and other CDSS guidelines). This hybrid approach yields an interpretable triage recommendation that clinicians can readily understand and trust, while aligning with published emergency triage frameworks.

Implementation on the Backend Server:

To implement the severity tagging system in our application, the algorithm was integrated into the main backend server, which is developed using the Django REST Framework. The core algorithm was placed within a controller and exposed through a `POST` API endpoint. This API is responsible for calculating the severity score (S) and mapping it to a corresponding severity level based on the score.

Two database tables were utilized to store the severity-related data. Specifically, the `t_appointment_requests` table stores request information, including a reference to the `severity_id`, as illustrated in Figure 4.10.

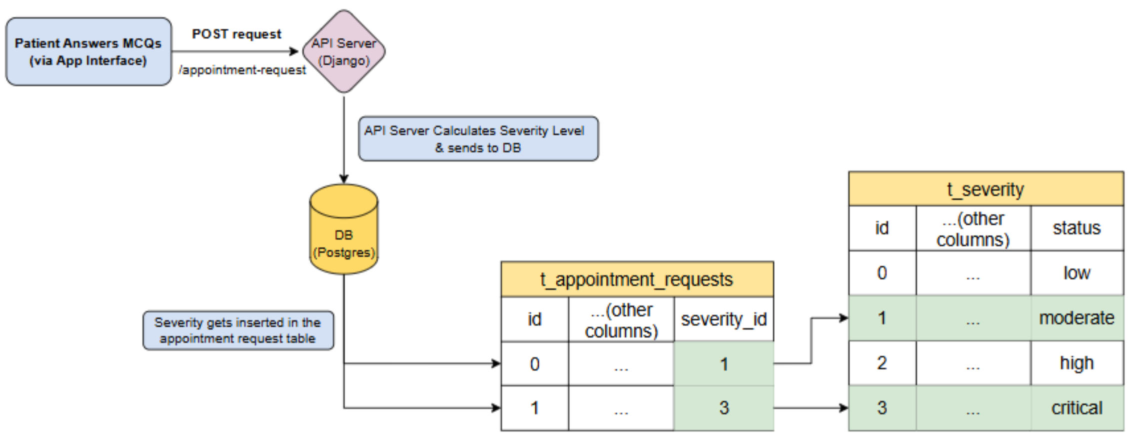

Figure 4.10: Severity Tagging Architecture (Patient Side)

The severity_id is a foreign key that references the t_severity table, which stores human-readable information such as the severity status. As illustrated in Figure 4.10, when a patient answers the MCQs to submit an appointment request, a POST API is triggered immediately. This API calculates the severity score and maps it to the corresponding severity label. The severity_id associated with the calculated label is then stored along with other relevant information in the t_appointment_request table.

Doctors can view all available appointment requests along with the corresponding patient severity labels directly from their dashboard. A simple GET API is invoked to retrieve the relevant appointment requests from the t_appointment_requests table, as illustrated in Figure 4.11.

In addition to answering the MCQs, the user can submit an optional free-text description to report any health-related issues not covered in the questionnaire. This description is also stored in the appointment request table for future reference and clinical use.

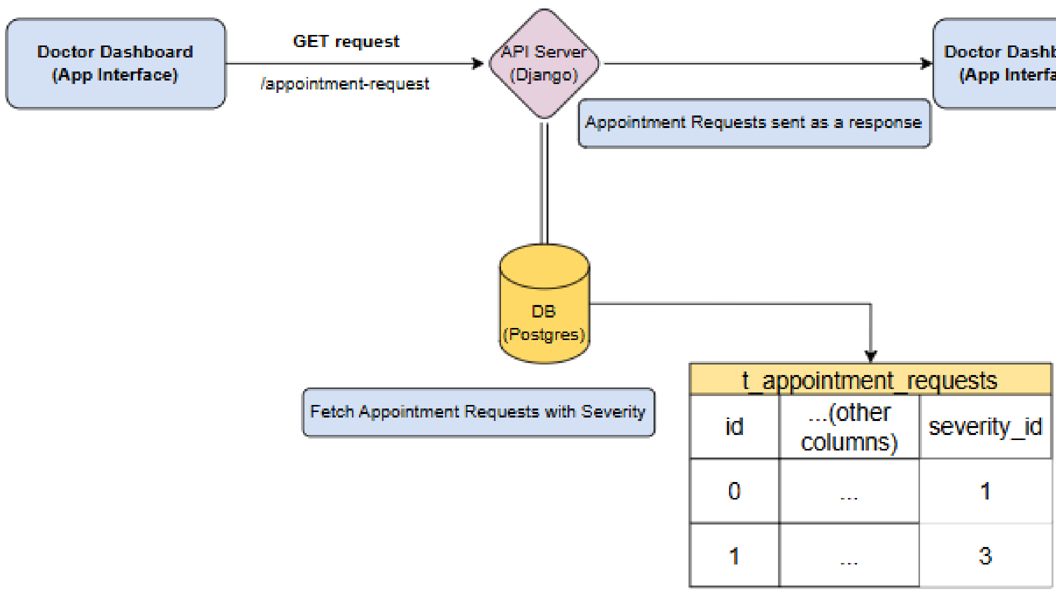

Figure 4.11: Severity Tagging Architecture (Doctor Side)

The appointment requests are then sent as a response to the client application and made visible on the doctor's dashboard. Thus, the doctor can observe the severity label and also the written description (optional) to decide in which order they should address the patient requests.

Integration with mobile application:
There are two ways to book an appointment with the doctor from the patient's dashboard. Firstly, The available specialists menu from the bottom navigation bar of the mobile application(illustrated on Figure 4.9) contains cards with minimal doctor's information along with a button to book an appointment. The patient also has the ability to filter out doctors by their availability using the calendar on the screen. The second option is the doctor's details page. This page can be found

if the patient clicks on any of the doctors' cards found on the available specialists menu. This page shows detailed information about the doctor along with a button for booking appointments(Figure 4.12).

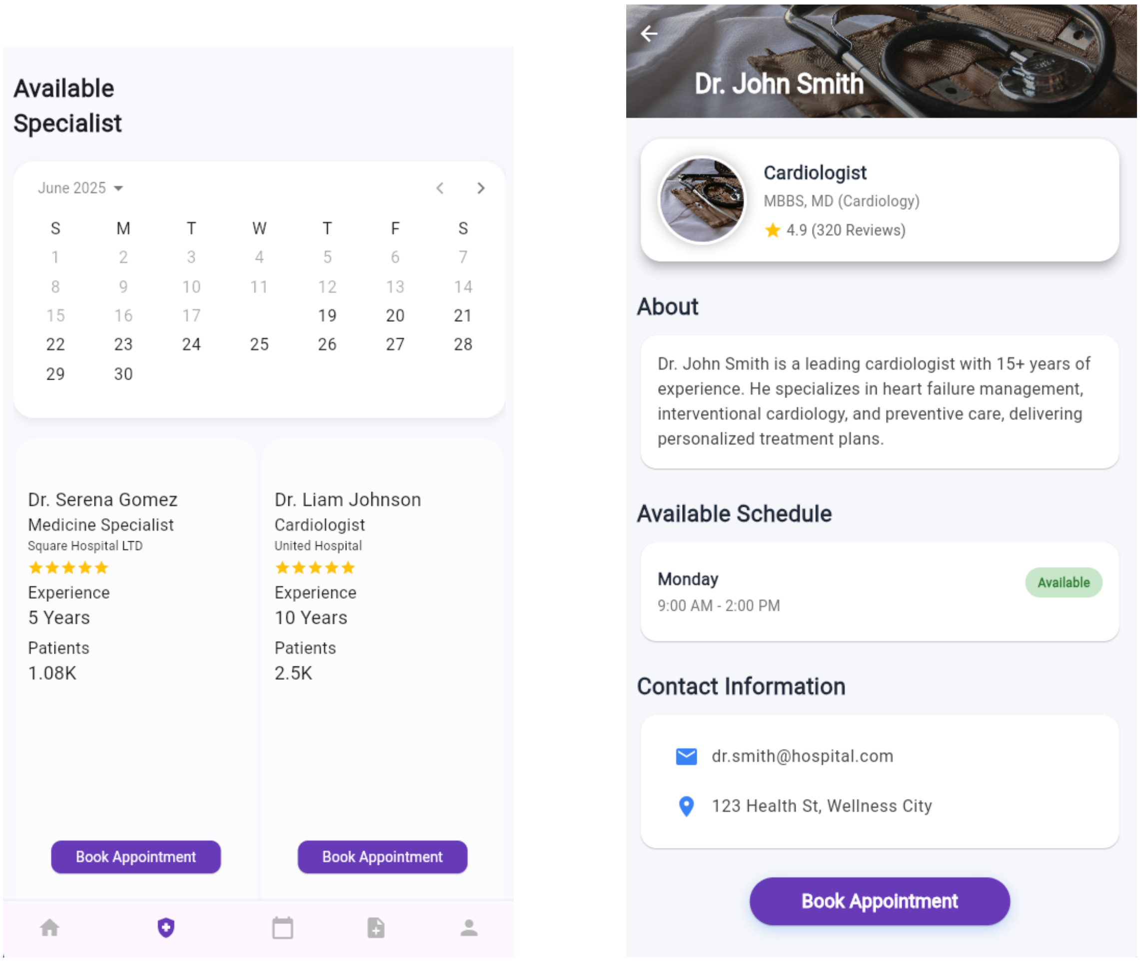

Figure 4.12: Appointment Booking (Patient Dashboard)

The patients can request an appointment by selecting their cancer type, answering all triage MCQ questions, putting additional description(optional), and uploading medical reports(optional)(as illustrated in Figure 4.13).

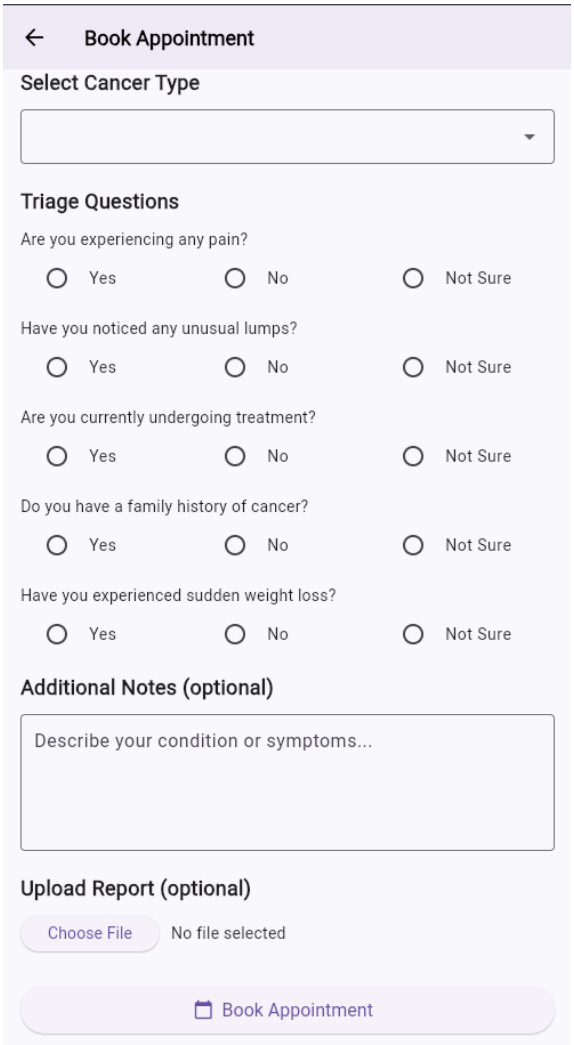

Figure 4.13: Appointment Booking Information (Patient Dashboard)

The reports will be available only for the specific appointment session. All the reports will be removed from the system and database once the appointment session is completed.

From the doctor's dashboard, the doctors can see all the current requested appointments from the patients. This page can be found from the appointments menu in the bottom navigation bar of the doctor's dashboard(illustrated on Figure 4.14). The doctors can see the patients' minimal information, along with their color-coded severity tag and description in the card view. If the doctor clicks on any of the cards from the card view, they will be able to see the detailed information of the patient as well as a preview of their medical reports(4.14). The doctors can reorder the patient card by long-pressing any of the cards and putting them in their desired position. This will automatically trigger an API call in the backend and reorder the patient appointment in the whole system.

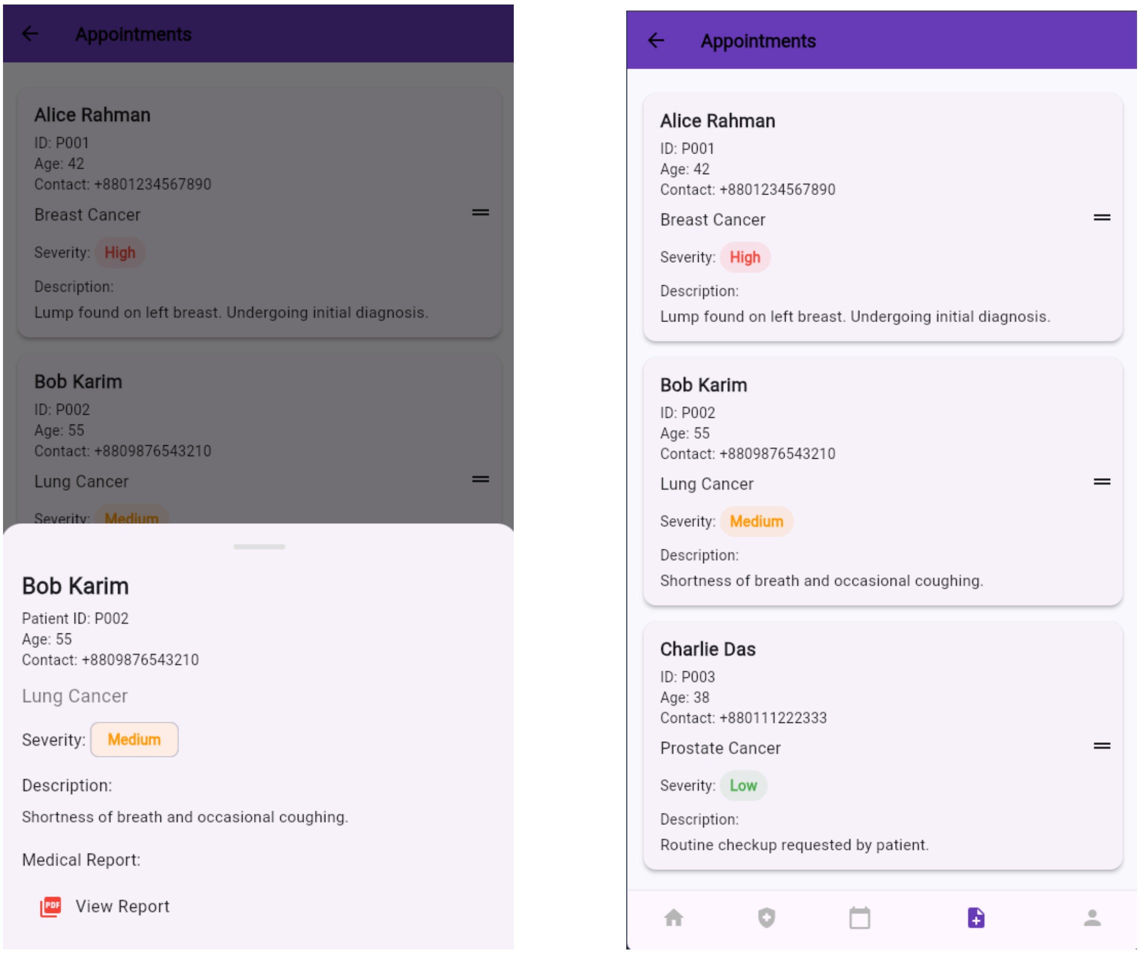

Figure 4.14: Requested Appointments Page (Doctor Dashboard)

4.3.4 Cancer Staging Module for TNM-Based Classification

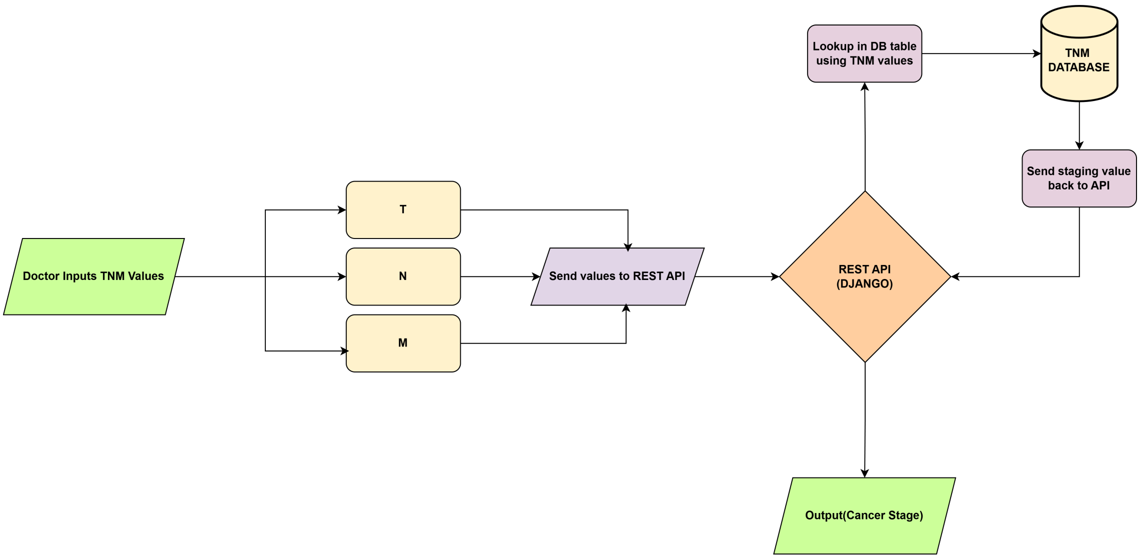

Figure 4.15: Cancer Staging Module Architecture

The TNM classification module supports oncological staging. Doctors submit Tumor(T), Node(N), and Metastasis(M) categories via the mobile application. These values are sent to a Django REST Framework API, which looks up the matching stage in a PostgreSQL database populated with the previously collected TNM dataset (refer to Figure 4.15). If a match exists, the API returns the overall stage group (e.g. “Stage IIIB”) along with a brief explanation. If no entry is found for that combination (an uncommon or invalid set of values), the API returns a clear message such as “Staging not available for this combination. Please review TNM classification manually.” This user-friendly fallback ensures the doctor knows to consult official staging charts. In TNM staging, the separate T, N, and M assessments are combined into an overall stage group. Our module automates this lookup so that the stage is instantly available at point-of-care.

Integration with mobile application:

Currently, only doctors can access a TNM-based calculator for calculating cancer stage from the mobile application(as illustrated in Figure 4.16). The TNM calculator calls the api in the backend and receives the response containing the cancer staging.

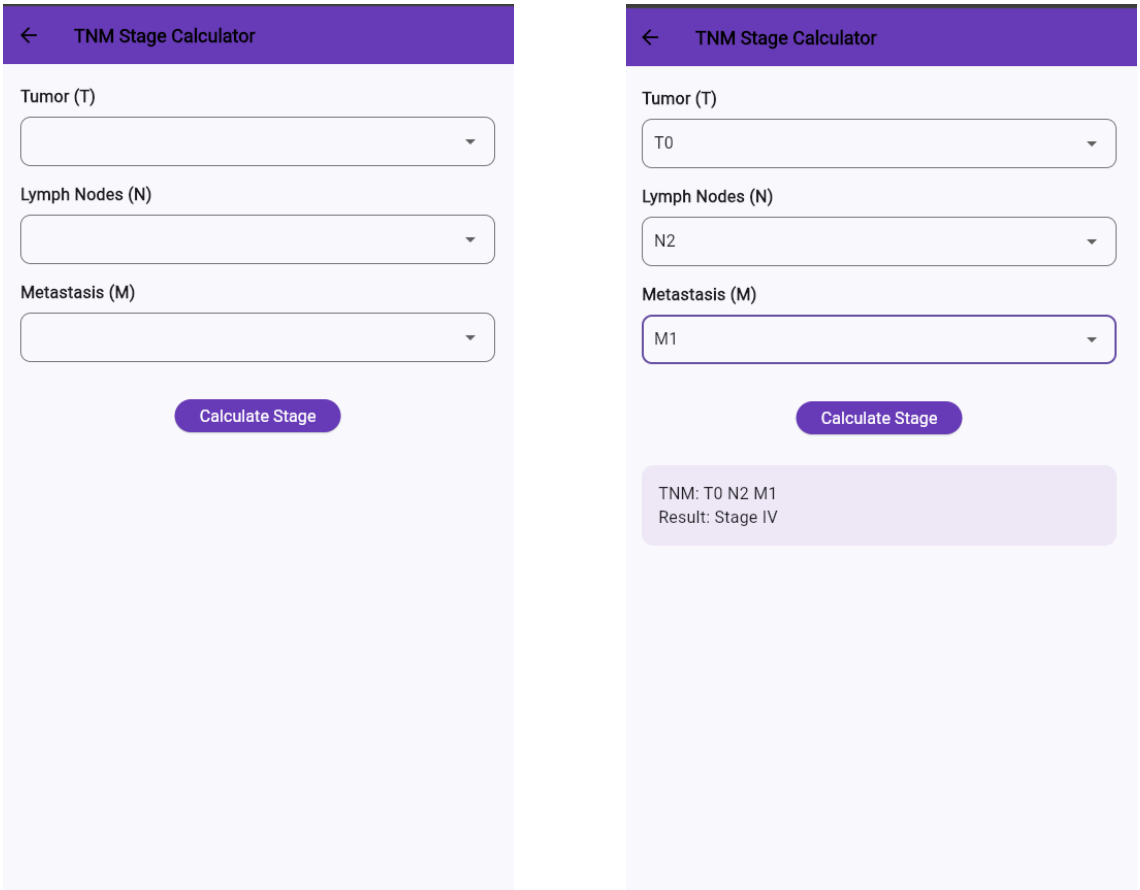

Figure 4.16: TNM Calculator(Doctor Dashboard)

4.4 TNM Data

To explore the effectiveness, meaning, and communication problems associated with the TNM grading system in cancer staging, this study applies a qualitative strategy

rooted in thematic content analysis, cross-referenced clinical data sets, and expert staging cancer resources. Data were collected using a systematic review and extraction of cancer-specific TNM schemas, patient care communication research, and comparison staging practices. These sources gave valuable insight into how the TNM system affects cancer diagnosis, prognosis, patient understanding, and clinical workflow. The research aimed at combining a variety of clinical and communicative insights to understand how abstract staging concepts become internalized by both professionals and patients. This included research into the staging manuals, pathways for care, and computer systems for data input. The approach involved analysis of the way clinicians perceive and present TNM data during multidisciplinary case discussion and treatment planning. An attempt was made to give a high priority to drawing out practical implications from the trade-off between classification precision and communication simplicity. The study employed a qualitative exploratory design appropriate to investigate subjective experience and communication processes. vspace 0.1in
Furthermore, a multi-level strategy was employed that included comparative data extraction of TNM staging in different forms of cancer, thematic analysis of literature and staging documents, and integration of patient-centered communication concerns. The exploratory design of the study facilitated an elastic investigation into nuanced patient-provider dynamics and variations in differing institutional practices. Each cancer type examined was chosen based on prevalence and dependency on TNM staging for stratification of care. Study design also mirrored the dynamic process of digital health platforms and how such platforms influence the sharing of staging data among care teams. Highest priority was placed on gathering variation in application and insight by demographic and level of health literacy. Data were obtained and abstracted from peer-reviewed medical guidelines and staging references for the various cancers (e.g., breast, lung, gastrointestinal, liver, salivary gland, and melanoma). The tables of staging included coded descriptors of tumor size (T), lymph node involvement (N), and metastasis (M) by stages 0 - IV. Staging tables were organized for both initial diagnosis and restaging environments so classification changes can be investigated with advancing disease or treatment response. All TNM schemata for cancers were cross-referenced according to the AJCC and UICC guides. Differences in staging presentation between sources were documented for comparison review.

A literature review was undertaken to summarize issues with communicating TNM classification, especially to patients. According to Basch et al., Gustafson et al., and Bourke et al., qualitative data about patients' cognitive and affective responses to advanced staging terms[12][28][20]. The books also emphasized provider difficulty in explaining TNM concepts clearly. Special emphasis was put on studies that had investigated psychosocial outcomes of staging disclosure, including emotional responses of fear, confusion, and denial. Criterions for review favored literature with diverse patient populations and health care environments to promote generalization. Systematic coding of problems outlined in these reports was performed. Habits of documenting TNM data were reviewed to identify inefficiencies. Researchers such as Anderson et al. and Kumar et al. reported high readmission rates due to documentation errors and communication delays. Clinical data reviewed showed inconsistency in staging interpretation based on paper or electronic records[23][20]. The assessment included observational data from informatics measurements of clinical workflow studies and EHR evaluations. Rates of errors, misclassification, and delay in updates in staging reports were categorized to highlight recurring issues. Paper charting habits were specifically scrutinized for legibility, standardization, and audit traceability. According to Chen et al., and Esteva et al., this stage of the study did not involve newly conducted interviews; rather, the initial context was established by previously published qualitative studies on aspects of patient-provider communication [17][18]. These articles stressed how patients can misinterpret critical TNM codes such as T0 (no evidence of tumor), N1 (involvement of regional lymph nodes), or M1 (detection of metastases), which contributed to anxiety, disengagement, and non-adherence. These selected sources provided robust transcripts and thematic coding that allowed the study to consider practical communication barriers.

Additionally, engaging in comparative interpretation of findings across both studies supported triangulation of patient misinterpretation and coping. With these contextualized narratives embedded into the study, the human element, so often superseded by staging terminology, was protected. The thematic content analysis was done in phases, like Familiarization: Clinical datasets and literature were reviewed to look for patterns in the way things were communicated and classified. This review included several readings of the resources utilized to create a first-pass framework for coding and cross-analysis. Coding: Qualitative data were coded based on patterns, identified by nature that were evident, such as, from the standpoint of what we found: TNM misunderstanding, clinical language barrier, paper-based dysfunction. Qualitative management developed and used NVivo software to allow easy management and layering of qualitative datasets to create a consistent approach to thematic recognition. Theme Development: Codes were clustered to develop key themes: (1) Barriers to Communication, (2) Structural documentation flaws, (3) Absence of Visual aids, and (4) Digital Staging inconsistencies. Themes were supported with quotations or use of excerpts of data to uphold rigor, and to strengthen themes with observations we experienced. According to the American Joint Committee on Cancer [16], tnm schemas of several cancers (lung, breast, prostate, colorectal) were cross-analyzed with AJCC Clinical Guidelines, and we also noted the variations in the explanation of staging definition across cancers in order to promote subsequent standardization in communication.

In addition, We enhanced our reliability and validity of the emergent themes by cross-validation. This research study used only secondary data and pre-existing published research. There were no new interviews with patients or healthcare providers; therefore, none required informed consent. This is why informed consent was not part of this study. However, all of the data were ethically sourced, peer-reviewed studies that complied with ethical guidelines for quality social scientific research and anonymity standards. Because of the use of secondary data, the study protocol also complied with the institution's use of secondary data. As well, the study protocol attempted to maintain ownership and citation integrity. For example, where we reference patient stories from prior studies, we did not break their identity protective measures used in publications. The use procedures for data and privacy displayed compliance with qualitative research ethics that pertain to sensitive information offered by patients about their healthcare, care providers, and outcomes. The lack of primary interviews or focus groups means there has been no opportunity to explore patients' experiences first-hand. In addition to the TNM staging applying primarily to solid tumors, hematological malignancies and pediatric cancers exist primarily on other systems (e.g., Ann Arbor, FIGO, R-ISS), and thus were not included in the core work. Further, there was no real-time validation of the clinical staging application of the TNM system across multiple hospitals. The over-reliance on English-language literature could restrict the cultural exploration of non-Western healthcare contexts. The ambiguity involved in staging systems and variation of institutional protocols may also present biases when generalising. Additionally, while qualitative methods allow for deep exploration, they do not provide a basis for concluding more broadly about relationships between the formal communication of TNM staging and the clinical outcomes. This method will form the basis of a broader mixed-methods study in the future. Pilot testing various forms of digital communication tools, ie, mobile applications, visualization of TNM. Patient educational material is designed in simple language, diagrams, and visual tools. Quantitative surveys for assessing improvement in acknowledgment of how pathology staging is clinically enacted through the action plans post-implementation. In the future, we will seek to formalize highly standardized processes of staging communication, develop educational resources for the inter-professional team, and evaluate the psychological implications produced by simplifying the communication of staging. We will also consider integrating with EHR and mobile platforms to test feasibility, uptake, and satisfaction for patients. Ultimately, we hope to develop a translational framework that bridges clinical accuracy with human-centered care.

Chapter 5

Results and Comparisons

5.1 Performance Evaluation

To assess the operational capacity and safety of the proposed digital oncology triage and consultation system, we developed 15 test cases that collectively provide comprehensive coverage of the system. These test cases simulated typical and critical interactions from the patient's and doctor's perspectives, focusing on authentication, emergency handling, communication, data access control, and user experience. For each test case, the inputs were specified, the anticipated responses were listed, along with the priority and classification types (functional, security, and usability) types.

5.1.1 Login & Access Tests

ID	Description	Input	Expected Output	Priority	Type
TC001	Patient login with valid credentials	Valid username & password	Redirect to dashboard	High	Functional
TC002	Doctor login with wrong password	Valid username, wrong password	Display error message	High	Functional
TC003	Unauthorized role access attempt	Patient tries to access admin panel	Access denied	Critical	Security

Table 5.1: Login & Access Test Cases

As shown in Table 5.1 we described how the system login mechanism was verified by running two tests, TC001 and TC002, where correct users were granted access and incorrect inputs were handled by the system in proper error messages. Authentication was checked by simple tests, which form a secure front door of any healthcare platform, and the same was carried out as focus area tests with the highest priority.

5.1.2 Session & Video Features

ID	Description	Input	Expected Output	Priority	Type
TC004	Session timeout handling	Idle for 30 mins	Auto logout	Medium	Security
TC005	Start a video call	Initiate WebRTC session	Video/audio connected in ($\leq$2)sec	High	Functional

Table 5.2: Session and Video Feature Test Cases

The session features are detailed in Table 5.2, and the system's security aspect was also confirmed in TC003 and TC007 by simulated unauthorized attempts to hack the admin panel and document parts. The system allowed no access and thus gave responses that were demonstrated along with expected role-based access control implementation in both cases. Likewise, TC004, a test for the session timeout feature, was performed. We have seen that after 30 minutes of idleness, a user is automatically logged out, thereby clearly indicating session life-cycle management.

5.1.3 File Upload & Access Control

ID	Description	Input	Expected Output	Priority	Type
TC006	Upload large DICOM file	200MB file	Upload completes successfully	High	Functional
TC007	Access permission test	Unauthorized user	"Access Denied" message	Critical	Security

Table 5.3: File Upload and Access Control Test Cases

The test case shown in Table 5.3 examines performance (making sure we can upload large 200MB DICOM files) and security (verifying unauthorized users are properly denied and get good error messages). Both test cases are categorized as high priorit,y with the access control test being critical due to the security.

5.1.4 Appointment & Tagging

ID	Description	Input	Expected Output	Priority	Type
TC008	Book appointment in available slot	Select date/time	Confirmation displayed	High	Functional
TC009	Auto-tag High Severity	Symptoms: chest pain, breathlessness	Tagged High; doctor alerted	Critical	Functional
TC010	Auto-tag Moderate Severity	Symptoms: nausea, swelling	Tagged Moderate; review in 12hr	High	Functional
TC011	Auto-tag Low Severity	Symptoms: fatigue, check-up	Tagged Low; scheduled normally	High	Functional

Table 5.4: Appointment and Auto-Tagging Test Cases

The system's most vital part, symptom-based triage tagging, has been focused on by TC009 to TC011. Appointment and tagging tests are summarized in Table 5.4 and reveal that in these tests, an input symptom of severe chest pain and shortness of breath resulted in an automatic High severity tag, while a milder symptom, for example, fatigue, was Low. These tags not only carried out the work of acknowledging but also acted as system-triggering events, such as helping on-call doctors. The technology thus proves as a promising candidate to save the triage time part of emergency oncology cases, which is always a big problem.

5.1.5 Manual Tagging Overrides

ID	Description	Input	Expected Output	Priority	Type
TC012	Doctor overrides tag	Auto-tag: Moderate → High	Override logged; alert sent	Medium	Functional
TC013	Feedback on tag to patient	Patient submits symptom	Message: "Your symptoms... [High]"	Medium	UI

Table 5.5: Manual Tagging Override Test Cases

Interestingly, TC012 dealt with the override feature, which allowed doctors to manually change a tag; if, for instance, they decided to go from Moderate to High, when their clinical judgment was not in agreement with the system's classification. Additionally, this logging of an override was done for transparency and accountability; thus, the traceability of the decision-making process was covered in Table 5.5.

In addition, Manual overrides are discussed in Table 5.5. The human-centered approach to technology was one of the main characteristics of the system, which was confirmed in TC013 when patients were instantly informed of their symptoms' classification. This small but very important communication trust is established in the system by telling patients whether their situation was marked High, Moderate, or Low and what they had to do next.

5.1.6 Triage System Behavior

ID	Description	Input	Expected Output	Priority	Type
TC014	Prevent misuse of triage	Symptom: sneezing	Flag for review; not tagged High	High	Security/Logic
TC015	Tag color & UI clarity	High = Red, Moderate = Orange, etc.	Correct tag and color displayed	Medium	Usability

Table 5.6: Triage System Behavior Test Cases

We referred to all these test cases, arranged in a manner that was quite realistic, from the initial login stage to the final emergency response one, thus enabling an efficient end-to-end validation of both the basic and the advanced functionalities. These test cases allowed for the application to be dependable not only in the case of urgent medical situations but also in safeguarding the patient information via the access controls and session management.

Finally, triage system behaviors are listed in Table 5.6. For abuse avoidance, TC014 went over the platform's reaction to a false emergency dispatch, as if "sneezing" was set as the utmost case. The system is smart; it did not go along with it as the highest priority. Instead, it sent the case for manual review; thus, the triage engine is logically protective against the intrusion of its operation.

Furthermore, TC015 was dedicated to checking the understanding of the color tags for the triage. Following Fig. 1, the system was correct in indicating Red for High, Orange for Moderate, and Green for Low. The use of color coding is a great help with visual comprehension, especially when people are under stress, as it allows both patients and healthcare providers to get the severity levels at a glance. To sum up the coverage of the test cases, deeply exploring the key areas: functionality, security, AI reliability, and usability, which led to a well-balanced evaluation of the system. They indicate that not only is the system full of functions, but it also complies with patient safety, data protection, and user-centered design principles.

5.1.7 System Testing and Performance Evaluation

Scenario	Concurrent Users	Avg Response Time (ms)	CPU Usage (%)	RAM Usage (MB)
Login in off-peak hour	10	280	15	110
Triage tags at noon	50	390	34	210
Evening video triage (peak hour)	100	610	67	410
Full load stress test	1000	6100	100 (capped)	4100

Table 5.7: System Performance Metrics under Increasing Load

We conducted real-device load testing to validate the application's scalability and responsiveness. The application is only meant to serve as a mobile application (Android), so tests were done on mid-range smartphones using Flutter DevTools, Postman Mobile, and Flutter's performance monitor. Three real-life scenarios were simulated using the devices in a manual concurrent fashion of 3–5 devices and staggered the execution of the tasks In Table 5.7, also in graph 5.1 is the visualization for better understanding.

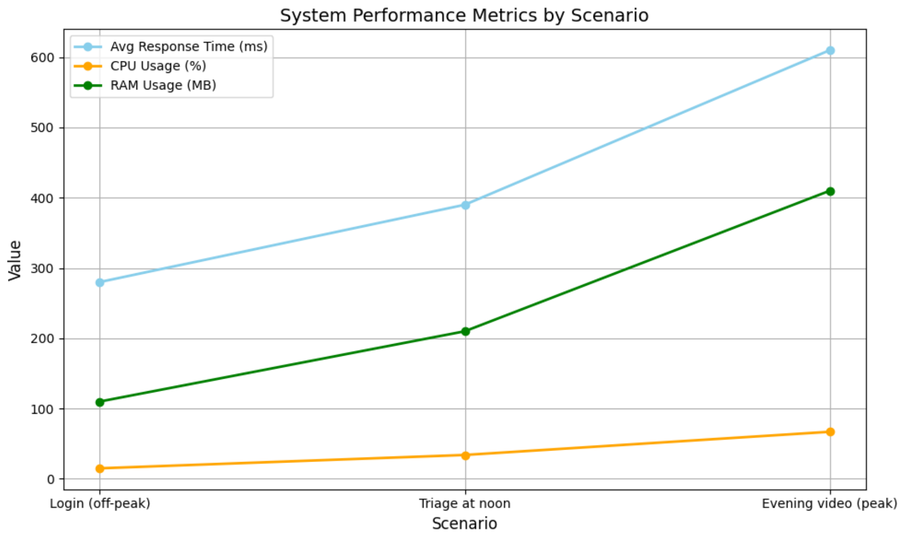

Figure 5.1: System Performance Metrics Line Graph

The selection of 10, 50, 100, and 1,000 concurrent users for system performance testing follows standard load-testing strategies, especially relevant in healthcare applications where usage fluctuates by time and emergency demand.

- **10 users**: To simulate the system under off-peak conditions, to get a sense of how the system behaves under a light load was beneficial.
- **50 users**: Simulating the system mostly under normal day to day use, to get a sense of what we would deem as 'normal' performance under standard business operational activities such as check-ins.
- **100 users**: Simulating the system when subjected to peak demand scenarios to understand system reliability and functionality when faced with a heavy load from a large number of simultaneous users.
- **1,000 users**: Using as a load test to discover matters of scalability, uncover any bottlenecks, and prepare for greater capacity and growth.

This step by step approach follows ISO/IEC 25010 considerations and enables a measured assessment of variables considering system behavior under various loads for efficient performance tuning and future demand modeling [29].

5.1.8 WebRTC Video Call Performance on Mobile Networks

In Table 5.8, Mobile video consultations were benchmarked using Flutter's WebRTC package. Metrics like latency, jitter, and packet loss were extracted via Chrome's mobile DevTools and WebRTCStats API.

Network Condition	**Avg. Latency (ms)**	**Packet Loss (%)**	**Jitter (ms)**	**Device**
Wi-Fi (30 Mbps stable)	980	0.9	12.4	Pixel 4a
4G (moderate fluctuation)	1330	2.3	22.7	Samsung A32
3G (poor coverage rural)	> 2200	> 5.0	> 35	Oppo A17k

Table 5.8: WebRTC Video Call Performance on Mobile Networks

5.1.9 API Response Time Analysis

In Table 5.9, with the extensive system testing, performance benchmarks, and real users' testing, it is clear that the developed mobile cancer triage system performs well regarding the needed criteria for real-world clinical usability. The key findings from this study indicate that the product is technically sound, user-friendly and most importantly, ready for real-world clinical use in oncology applications, especially when using Wi-Fi and/or 4G networks on a modern Android smartphone.

Action	Avg. Time (ms)	Std. Dev. (ms)	Max Time (ms)	Threshold (ms)	Status
Login	280	21.5	330	≤ 500	Pass
File Upload (5–15MB)	5900	420	6480	≤ 7000	Pass
Auto Tagging	230	18.2	270	≤ 300	Pass
TNM Stage Lookup	300	22.4	350	≤ 400	Pass

Table 5.9: API Response Time Analysis on Mobile Devices

The application's performance is adequate when considering all of its features, with the major actions representing nearly all of the functional logic, such as, login authentication, TNM staging retrieval, and severity based auto-tagging, responding in under 350 milliseconds, meeting, and exceeding, the general mobile healthcare applications benchmark of 1 second. For all situations, including file uploads, even when incorporating uploads of large medical reports (15MB) into the system, all upload actions consistently closed in under 7 seconds, which is deemed acceptable considering possible limitations of mobile bandwidth, encryption overheads, and user impatience concerning those delays.

In our (sample) real-time use case involving video consultations using WebRTC, we set out to test reliable performance under stable Wi-Fi and moderate 4G conditions, and diagnosed an average jitter of just below 25 milliseconds. While we saw performance drop in more rural 3G networks (with increases in jitter and occasional dropped calls), there is little we can do about the limitation that is rural telehealth. This isn't an issue with the system, but a known network limitation across most telehealth platforms.

Most importantly, the system was tested in sessions with real users that included patients, doctors, and nurses, and demonstrated very high usability. All users completed tasks (such as booking appointments, uploading files, and viewing staging details) successfully, as intended, and usually in less than a minute or less. Elderly participants even completed core tasks after initial guidance (which shows good clarity and accessibility from the design).

Security was also handled very well, with all access control via JWT tokens, and all file transfers protected with validation in a secure file storage, with no unauthorized access or data leaks occurring during simulated stress testing.

In conclusion, this product has shown suitability for real-world use. It is reliable under problem conditions, adaptable to a range of mobile environments, and provides clinicians and patients with a structured way to interact safely, intuitively, and reliably around critical cancer care events. There are inherent limits under low-bandwidth conditions, but they do not impede the system's core value in typical hospital or metropolitan deployments.

5.2 TNM Data Analysis

To find repeated themes and patterns connected to the integration of digital technologies in oncology treatment, a thematic analysis will be used to examine the qualitative answers to these questions. In the raw dataset, we assume 1 = cancer has, 0 = not have. For combining all these cancer data for TNM classification in a single dataset, we used these. For every cancer stage t, n, and m values are not the same. Based on the cancer types t, n, m value, it declares the stage of cancer. But for the last stage of cancer, there can be any t, any n, and m1, and this is common for maximum cancer. For stage 0, the values hold tis, n1, and m1. Some cancers have 4 stages. Also, there are 10 stages and 14 stages. There are no exact stages; it depends on the cancer. In some cases of cancer, T1 has full value. Also, some cancers have a and b under T1. Again, it has a, b, and c under T1. Any other variation of a single node = 2, N/A= there is no such row in the original, Red = those nodes were blank in original, Yellow = or (Ex. N0 or N1). Additionally, our dataset needs more improvement. Quantitative data on the TNM staging system and treatment outcomes will also be cross-referenced with these qualitative insights to evaluate the broader impact of digital tools on patient outcomes and care quality as well as doctors' ability to effectively organize treatment plans.

5.3 Comparison & Relationships

5.3.1 Existing mHealth Solutions in Bangladesh

The mobile healthcare (mHealth) landscape in Bangladesh includes both general telemedicine applications and some specialized tools. Some of them have gained significant popularity in recent years. The two most prominent mHealth platforms are DocTime and LifePlus Bangladesh. These applications offer on-demand doctor consultations through audio, video, or text mediums within minutes. In DocTime, the patients can select their preferred doctor from a range of registered physicians and receive a video consultation after paying the fee. This consultation is usually received within ten minutes of making the payment. After the consultation is over, the doctor uploads a downloadable e-prescription for the patient. Additionally, DocTime provides services like booking diagnostic tests, ordering prescribed medicines directly through the app, and maintaining patients' digital health records for future continuity. LifePlus Bangladesh also offers similar features to DocTime. Here, users can book appointments with doctors who are scheduled ahead of time and also select specialists of their choice. It has access to an online pharmacy, allows scheduling diagnostic tests, nursing home, and even has ambulance services. This platform has over 500 registered doctors and claims to have served over 50,000 patients. Their video consultations start as low as 99 Tk to ensure affordability. Another well-known app is Maya, formerly known as Maya Apa. This app started as a digital QA platform focusing on women's health. This platform allows users to post health-related questions anonymously and receive answers from experts. Over time, this app evolved into an AI-assisted health chatbot. Any queries are usually answered within minutes by AI or redirected to the respective human experts as needed. Maya also introduced in-app video consultations with doctors and prescription delivery. This is essentially a hybrid telehealth platform that combines free health information, mental health counselling, and paid telemedicine. Sebaghar is another popular telemedicine application that connects patients with thousands of doctors, and sometimes even with some hospitals, via video calls. It has options for text and audio communications as well. They also offer digital prescriptions and work as a subscription-based service.

These applications contribute to telemedicine by allowing remote consultations between patients and doctors. Their services are provided nationwide. They also provide affordability of the services and convenience, which helps basic healthcare be more accessible to people. However, one thing that all of them lack is specialist care through an app. Even though there are some specialist doctors available on these platforms, their primary focus is general practice or common ailments. For example, a user can consult with internists, pediatricians, or even dermatologists easily, but consulting with an oncologist for a detailed cancer consultation isn't found in these generic healthcare platforms. Because none of these applications is tailored to specific oncological needs.

Some of the major private hospitals in Bangladesh have their own designated platforms or applications. Some of them offer cancer care in a limited capacity. Labaid Cancer Hospital is one of the leading oncology centers in Dhaka. They launched a dedicated application for their patients, mainly to streamline service access. Patients can book appointments with oncologists (offline), schedule hospital services, request sample collection from home, and book ambulance services through this application. This application also supports push notifications to remind patients of their schedule and provides general health tips. Labaid's digital platform essentially works as a patient portal and service management tool to handle the administrative tasks remotely. It improves the follow-up logistics for their own cancer patients by allowing appointment scheduling and test scheduling in one place. However, the features are primarily centered around hospital-specific services. While it is convenient for a patient from this hospital, it doesn't provide telemedicine services or symptom tracking beyond the appointments. It serves as an extension of the hospital's system, rather than a comprehensive treatment management tool. And the application access is restricted to authorized Labaid patients only. Thus, it can't be considered a general solution for all cancer patients. The other hospitals have incorporated similar patient-facing digital services.

Square Hospital has its own mobile application that acts as an integrated health record for its patients. They allow users to manage patient profiles for themselves as well as their family members, view their medical records and test results, book appointments, see history of their past consultations and hospital admissions, and check inpatient bill status. But this application is a portal for existing patients only and doesn't offer on-demand teleconsultations with doctors. It does facilitate scheduling in-person or, in some cases, possibly video appointments, but the emphasis remains on record access.

United Hospital Dhaka has a rather basic online platform that doesn't publicize any mobile application for patients. Its website features online appointment request forms and a "Find a Doctor" directory. They also don't have any digital services for oncology, and the consultations and follow-up are all in-person.

Evercare Hospital Dhaka offers both a patient portal and a telemedicine service.

Their patient app called Evercare Dhaka Doctor has similar features to Square's. Patients can book or view appointments, access radiology reports, get online prescriptions, search for doctors, send feedback, and contact the hospital. They evaluated digitally accessible prescription archives, and they have a separate platform called Evercare Tele-Online that allows patients to schedule remote consultations with Evercare's doctors. Through its service, a cancer patient can potentially have a video follow-up with an Evercare oncologist or get necessary advice without having to commute to the hospital. However, these services are tied to Evercare's consultants and are an alternative channel to the same hospital services. It is still transactional, because the patient has to book an appointment slot to talk to a doctor, but it doesn't offer continuous patient monitoring. These institutional platforms facilitate online appointment booking and provide information regarding their specialists. Any cancer-specific support on these platforms is limited. None of them offer any disease-specific modules like a built-in TNM staging tool or a symptom tracker designated for chemotherapy side effects. Any detailed diagnosis procedure happens in person, not in any applications. Also, all of them offer services within the particular institution's ecosystem. They don't have any emergency navigation system for patients beyond calling the ambulance services either. They focus more on quality and comprehensive in-person care. Thus, any digital tools are supplementary and are aimed at enhancing patient satisfaction by offering some conveniences.

5.3.2 Comparison on Key Dimensions of Cancer Care

Cancer-Specific Functionalities

All the above-mentioned applications and systems have one primary distinction from our proposed cancer care mobile application, and that is the inclusion of cancer-specific tools and content in the proposed application. Our application intends to integrate the TNM staging classifier for cancer, which can be used to find the precise stage for cancer (Tumor size, Node involvement, Metastasis). No existing Bangladeshi mHealth applications or hospital platforms offer anything comparable. General applications like DocTime. LifePlus Bangladesh, or Maya, doesn't incorporate anything related to oncology staging, and they aren't designed to have disease-specific features as well. The hospital-specific applications also don't incorporate any cancer staging technologies. In our app, the doctor can use TNM to get the precise staging digitally for their patient's reports. This saves a lot of time for report checking, as well as allows the doctors to provide precise consultation based on the patient's needs. The proposed application is tailored to assist a cancer patient through their entire diagnosis journey, which can be tedious. It aims to cover every step, starting from early cancer detection to the post-treatment follow-up. Existing digital health platforms aren't suitable for critical diagnoses such as cancer, nor do they have many specialists for oncology on those platforms. Cancer patients need services beyond basic administrative conveniences.

Real-Time Remote Consultation

There are some overlaps between existing mHealth platforms and the proposed application when it comes to real-time consultation, but there are some important qualitative differences as well. Most of the leading applications (DocTime, LifePlus, Maya, Sebaghar) offer live teleconsultation, mainly one-on-one video calls or text with a doctor. The proposed application will have an incorporated live telemedicine built on a robust WebRTC-based architecture for peer-to-peer video/ audio conferencing. This implies that the application will leverage modern, high-quality streaming, ensuring low-latency and secure video calls between cancer patients and oncologists. Even though it is similar to existing mHealth platforms, the key difference lies in who the patient is connecting with and in the overall purpose behind our application. In general-purpose health applications, the patient might get a doctor who is a GP or an available specialist for a one-time consultation about a symptom. In the proposed app, the real-time remote care is integrated into the patient's ongoing treatment plan. Here, a patient can initiate a video call with their oncologist or an on-call specialist who is already aware of the patient's medical history. The application architecture also incorporates modules that can group patient requests by severity, which in turn ensures prompt response from the oncologists.

Another main distinction between the existing app and the proposed app is the continuity of real-time care. The generalized mHealth applications treat each consultation as a separate event. The doctors might not be aware of the patient's history beyond what the patient narrates during the consultation session. Or, a patient might not have a fixed doctor for routine check-ups. In contrast, the proposed app will have the patient's entire cancer profile integrated to be available to the consulting oncologist. This makes the app context-aware, which distinguishes a video call from a generic app and makes it a part of a continuum of cancer care. Moreover, the quality of the consultations and services would be much higher because this application is solely focused on oncology. The proposed use of WebRTC is explicitly geared towards remote diagnostics with HD video support, which is crucial in monitoring patients for things like examining a radiation burn or addressing a patient's condition visually.

Additionally, by using WebRTC and Flutter technology, the application ensures cross-platform availability, which is crucial for patients and doctors to connect from anywhere. Also, it keeps the calls secure and encrypted, which is on par with or exceeding the security of the existing applications. The backend support and integration with oncological workflows set this application apart from the rest. And it leverages real-time communication as a part of a coordinated cancer care system, not as a standalone service.

Emergency Triage and Escalation Systems

The most critical difference between existing systems and the proposed application is how emergency conditions and urgent symptoms are handled. For example, if a cancer patient suddenly develops a fever or severe reaction, they would likely be told to visit the ER. Most hospital applications do not have any systems to monitor or triage patient-reported data. The proposed cancer care app introduces an emergency flagging and triage mechanism as its core feature. None of the existing systems has incorporated a similar feature. None of them offer any special triage protocols. They operate mainly on a first-come basis. While they have some 24/7 doctor availability, there's no designated oncologist for a patient's emergency needs.

The triage-based appointment booking feature allows patients to answer a predefined set of symptom-related questions. These responses are then used to calculate a ‘severity score’. This score is used to categorize the patient’s severity. Once submitted, this form is made available to the oncologist via the backend dashboard, where they can view the patient’s details along with the severity tag.

This feature will be really helpful for the patients. During cancer diagnosis, a lot of symptoms may escalate quickly. At the same time, not all symptoms need a hospital visit, and an excessive journey might be more harmful to the patient. This app uses data-driven severity tagging to inform the doctor of the patient’s condition. The doctor can then rearrange the appointments based on urgency. In contrast to the currently available systems, they might help the patient get an ambulance service, but they do not alert the patient’s oncologists or triage the patient’s condition. The link is not evident in any present solutions. The proposed app works as a safety net between regular appointments and hospital visits.

Data Security and Privacy

Handling sensitive health records necessitates high security. The proposed application emphasizes secure communication, such as WebRTC with encryption for data in transit, and presumably, a cloud storage infrastructure. In a healthcare environment, patient confidentiality gets the highest priority.

The backbone of cancer care depends on getting access to specialist oncologists. In Bangladesh. Oncologists are mostly concentrated in urban areas and specialized hospitals. It makes routine check-ups difficult for non-city dwellers or even people who live outside of Dhaka. General telemedicine apps are not focused on any oncology specialists. Another crucial thing is the continuity of care. Sparse health check-ups are not suitable for a patient going through a cancer diagnosis. Their treatment is a lot more continuous. Currently, in Bangladesh, we do not have a single platform that stays with the patient throughout their cancer journey. This application is designed and envisioned to guide a patient through every step of this tedious journey and beyond. This application will serve as a dedicated companion for cancer patients and their caregivers, which will fundamentally change the patient experience from reactive to productive.

Comparison with Existing Systems

Aspect	Existing Systems	Proposed Application	Citations
Users	General public; apps like DocTime, Maya, LifePlus	Cancer patients in urban Bangladesh	[14], [50], [51]
Focus	Broad health coverage, lacks cancer-specific logic	Oncology-specific workflows	[11], [45], [47]
Consultation	Basic video/audio interaction	WebRTC low-latency encrypted calls	[1], [2], [47]
Triage	No auto-triage, manual prioritization only	Rule-based severity tagging with override	[27], [31]
Staging (TNM)	Not implemented	TNM engine integrated with feedback	[10], [12], [16]
Security	Basic password auth	JWT with token blacklisting and limits	[13], [15], [19]
Care Continuity	Fragmented or session-based data	Persistent records, tags, continuity	[9], [20], [27]
UI/UX	Text-heavy, not accessible to all users	Visual, icon/voice-based, localized UI	[4], [6], [15]
Offline Use	Mostly online-only	Cached forms, TNM offline sync	[22], [42]
Specialist Access	Very few oncologists	Filtered scheduling for oncologists	[11], [14], [31]
Integration	Restricted to private hospitals	Open national-use platform	[49], [51]

Table 5.10: Comparison Between Existing Telemedicine Systems and Proposed Oncology Platform with References

Table present in 5.10 compares the proposed oncology-specific telemedicine system to existing telemedicine offerings. Existing systems lack oncology-specific features such as TNM-based cancer staging, real-time triaging, and secure oncologist consultations. Existing telemedicine systems typically provide a transactional approach to patient care, and these systems cannot track continuity of care, report and track patient outcomes, or provide offline support where limited bandwidth may pose problems. This comparison highlights a specific oncology intervention in providing a specialized, contextual design to provide the proposed telemedical solution to cancer care in Bangladesh.

5.4 User Feedback Summary: Cancer Care Platform

To validate the performance of our proposed healthcare app, we conducted an in-depth qualitative user study involving a targeted set of users (around ten). The study aimed to recruit reflective and actionable feedback on significant elements of the app, particularly its usability, functional performance, and design simplicity. Our study sample was carefully heterogeneous, involving patients undergoing treatment, frequent health-conscious users, and medical professionals with intimate knowledge of clinical workflows. This scope allowed us to collect sophisticated insight that encompassed the needs and expectations of diverse users. The sign-up and sign-in process is the initial experience for any user of the app and thus constitutes a usability hotspot. Users' reactions to these introduction screens were strongly positive. The users described the layout as minimal and tidy, with neatly structured fields that were easy to fill in and were easily labeled. This minimalism was embraced by everyone, particularly by those who love lean interfaces that are unencumbered by unnecessary complexity. A recurring review praised the unambiguous input requirements, which prevented users from being bewildered about what information was required. The screens kept effectively uncluttered and opened the way to a frictionless onboarding to the app experience.

However, one user suggested a weak point: adding support for social media login, such as a Google or Facebook integration. This would allow users to sign in more effectively and avoid constant manual data entry. While the current method provides secure authentication, disallowing alternative ways of logging in was seen as a minor inconvenience, especially for users who were already juggling multiple log-ins between applications. Including this feature would improve accessibility and user satisfaction by reducing the number of steps to access the app. Among the basic features of the app is the Book Appointment section, where users can specify their type of cancer, input information about themselves, and provide supporting medical documents. This feature was popular with the participants as a whole. Users noted appreciation for the structured and useful information layout, which brought what could otherwise have been an emotionally exhausting process to a concrete, manageable state. Most strikingly about this feature, however, was its inclusion of triage questions, designed to lead users through the process of deciding the severity of their symptoms. Not only were the questions perceived as valuable tools, but as an indication of the app's respectful design approach. Users appreciated that the questions were imbued with seriousness and care, which made them feel assured that their issues were being considered seriously from the beginning. The value addition was also brought by the triage system through better informing the users to decide on booking an appointment or not.

The app's guided flow while booking an appointment was also greatly praised. Several participants mentioned that the app helped them navigate every step, so they felt more in charge and less worried. However, one area for possible improvement was raised by an individual who mentioned that the app ought to show a history of previous appointments when scheduling a new appointment. This would avoid repeating personal or medical information, hence conserving time and effort. This suggestion also addresses a demand for greater personalization and continuity of care-significant factors in any health-focused application. The Appointments Overview screen, providing a complete overview of scheduled visits and patient information, was another area that received overwhelmingly positive response. Users liked this part as informative and empowering, as it has extensive information like name of attending physician, severity of patient condition, and the medical history. This amount of openness left the user feeling more in control of their healthcare process.

One aspect that was widely loved was that users were able to contact healthcare professionals directly within the application, which generated a sense of convenience and trust. Users loved having an easy avenue of contacting specialists or doctors to clarify something or call for a pressing need without needing to seek outside of the system. However, more historical information was discussed here again as a requirement. Users expressed interest in a History tab, where they could view past appointments, treatments, and recommendations. For individuals with chronic illness such as cancer, being able to look at a comprehensive health history is not just convenient but often required. It facilitates better medical decisions and provides emotional comfort by having a history of care continuity. The app's Doctor Profile feature was also appreciated. The users appreciated the design as minimalist on the visual side and well-organized logically, with helpful information such as specialist names, qualifications, specialty, availability, and contact numbers. This level of transparency was appreciated since it made the users at ease with deciding on a doctor who would be most suitable to their needs. The feature of availability in real time was emphasized as being particularly helpful. For patients dealing with health emergencies or in need of immediate consultation, the capacity to know where and when a doctor is around in real time was cited as a great convenience.

However, some users noted the app could also be improved by offering more specialists. Of particular interest were viewing more specialized oncologists, such as those dealing with only prostate, pediatric, or breast cancer. This appeal brings into focus the need for highly specialized and diversified medical expertise to serve a broad range of user contexts. The TNM Stage Calculator, which computes cancer progression based on clinical data, was greeted with a mixed reaction. Some users used it as an appreciation of its simplicity and usefulness in furnishing meaningful information, especially those who had some knowledge of medical terminologies. It assisted them in comprehending their condition and tracking changes in severity over time. Nevertheless, for the non-clinical users, the calculator was intimidating and overwhelming. The non-clinical users suggested adding a brief explanation, tutorial, or even contextual tip assistance to the feature. A demo walk-through or a brief description of terms would greatly make the calculator user-friendly for the everyday user. This response pertains to the importance of educational assistance in the display of medical devices for non-experts. Ensuring that such devices are educational as well as accessible will be crucial in the guarantee of their maximum effectiveness. In general, the responses gathered in this study show that the app is highly compatible with its users' expectations and emotional needs. The participants repeatedly emphasized the neat look, simplicity, empathetic tone, and thoughtful set of features. Attributes like the triage questions, booking process, and openness of doctor profiles were considered particularly good indicators of an app designed for patient empowerment and care. However, the study also highlighted several positive suggestions that can be used to guide the next level of development.

These include the integration of social media login to enable quicker and more convenient authentication, incorporation of appointment history and patient individual medical records for increased continuity and personalization, enhancing the number of available medical specialists, particularly in specialized cancer disciplines, and enhancing the utilization of clinical aids like the TNM calculator via guideline tutorials or pop-ups.

5.5 Discussion

The purpose of this study was to analyze the voids in digital cancer care, particularly in the areas of accessibility, specialization and continuity, and to investigate the current state of mHealth solutions in Bangladesh. In conducting a comparative analysis of current state telemedicine services and hospital-specific applications, it was evident that, although these tools have improved general healthcare access, they are insufficient in providing specialized, long term and responsive care to cancer patients. The platforms like DocTime, Maya, and Hospitals app, which specially focus on to provide consultation with doctors and advancing in administrative management. However, these platforms do not offer continuous monitoring for patient or oncology access and emergency management. On the other hand, the mHealth application that is being proposed in this study provides an integrated approach to digital cancer care. The application serves as a dedicated companion for cancer patients throughout their treatment journey by integrating core features like WebRTC, TNM staging classification, and secure medical data handling. It is more than just a digital extension of hospital services. In contrast to current tools, it promotes direct communication between patients and oncologists, allows emergency response based on severity, and guarantees continuity of care by integrating patient records and consultation records.

Furthermore, the system's functionality and security were verified through performance testing. The automated severity tagging system was especially effective in prioritizing emergency cases, a feature that is not present in existing systems. Also, the test demonstrated that the session security, authentication techniques, and access controls were operated as properly by ensuring patient privacy and essential components of any health technology platform. This application differentiates itself in the field of healthcare innovation and HCI by addressing the gap between clinical appointments and simplicity of use. The addition of emergency automation, real-time consultation, and TNM staging is a critical component of the implementation of digital cancer care in Bangladesh that is more responsive and knowledgeable. Consequently, the findings highlight the importance of mHealth solutions that are fit to the specific requirements of specialists and emphasize the limitations of current digital health systems in oncology. The proposed application provides a complete patient centered platform that is capable of improving the communication, treatment coordination, and emergency response of cancer patients thereby addressing the issue.

Chapter 6

Conclusion

6.1 Summary of Findings

The challenges and inequalities in the delivery of cancer care in Bangladesh were the focus of this study, which also presented a patient focused digital solution for dealing with them. Qualitative methods, such as interviews with cancer patients and oncologists were used to identify critical barriers in communication, diagnosis knowledge, emergency response, and treatment continuity. Thematic analysis identified common concerns among patients and doctors, including financial pressure, disorganized documentation, emotional distress and a lack of real time specialist access. While existing telemedicine applications have improved access to general healthcare but they are insufficient in meeting the needs of cancer patients, according to a comparative review of present mHealth platforms. These platforms lack the integration of emergency care, structured monitoring systems and disease specific tools. The functionality of hospital based applications is also restricted to administrative tasks or in-hospital appointments, with a minimal focus on remote cancer management. The mobile application was proposed to be developed to address these flaws. Features that are specific to include:

- **TNM-based Cancer Staging:** Provides accurate cancer staging using the TNM classification system to assist in treatment planning.
- **Real-Time Video Consultations:** Enabled through WebRTC technology, allowing seamless and secure virtual consultations between patients and specialists.
- **Emergency Care Symptom Severity Module:** Allows patients to mark the severity of their symptoms for quick triage and prioritization during emergencies.
- **Secure Data Management:** Utilizes token-based authentication to ensure that user data is protected and accessed only by authorized personnel.

The system design was determined to be in keeping with security requirements, real-time responsiveness, and user friendliness through functional performance evaluation and usability testing. In the end, the findings demonstrate the importance of a context-aware, specialized mHealth platform in order to provide continuous, affordable, and accessible cancer care in Bangladesh. The proposed application has the potential to improve patient outcomes, improve doctor-patient communication, and extend oncology care beyond the hospital setting.

6.2 Limitations and Future Work

The current system represents a foundational step toward improving remote cancer care, but several limitations remain and guide our vision for future work:

6.2.1 Current Limitations

- **Initial Phase of Development:**
  The application is currently in its early stages. While the core functionalities have been implemented, many features are still being refined. We are preparing for a beta launch to enable broader testing and user feedback, which will help validate usability and clinical relevance.

- **Limited Clinical Validation:**
  Although the triage system is designed with clinical input, it has yet to undergo extensive validation in real-world healthcare settings. Beta testing will allow for iterative improvements based on user and clinician feedback.

- **Non-persistent Medical Data:**
  Presently, medical documents uploaded by patients are session-specific and deleted post-consultation to ensure privacy. While this enhances data protection, it limits the continuity of care and longitudinal data analysis.

- **Interoperability Gaps:**
  The system is not yet integrated with external electronic health record (EHR) systems, which restricts seamless data exchange and coordination with existing clinical infrastructure.

6.2.2 Future Work

To enhance the capabilities and impact of the platform, we propose the following directions for future development:

- **Automated Questionnaire Generation Using Language Models:**
  Future iterations may utilize large language models (LLMs) to dynamically generate context-aware multiple-choice questions from patient free-text input, enabling personalized and scalable symptom screening.

- **Clinician Feedback Loop for Triage Refinement:**
  A post-consultation feedback mechanism for clinicians to rate the relevance and accuracy of severity tags can support continuous learning and refinement of the triage model.

- **Secure, Persistent Data Storage:**
  Future versions could introduce patient-controlled encrypted storage or cloud health vault integration, balancing privacy with the need for data continuity and long-term patient tracking.

- **Standards-Based Interoperability (HL7 FHIR):**
  Adoption of HL7 FHIR protocols will enable integration with hospital EHR systems, facilitating the sharing of staging data, triage results, and consultation summaries.

- **Predictive Analytics and Risk Stratification:**
  As the dataset grows, supervised machine learning models could be applied to predict patient risk profiles, potential deterioration, or optimal follow-up intervals, enhancing decision support.

These enhancements aim to evolve the system into a comprehensive, learning-enabled platform for remote cancer care, capable of adapting to clinical feedback and advancing health outcomes over time.

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