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ANSd: A Digital Simplified Neurological Assessment Application to Support Leprosy Care

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Abstract

Purpose: Leprosy (known as Hansen’s disease in Brazil) continues to pose a major public health challenge in several endemic countries. The Simplified Neurological Assessment (from the Portuguese *Avaliação Neurológica Simplificada* - ANS) is the standard procedure recommended by the Brazilian Ministry of Health to evaluate nerve function in individuals affected by leprosy, and is essential for preventing irreversible disabilities. However, its manual implementation limits data standardization, follow-up, and integration into digital health systems. This study presents the ANSd (Digital Simplified Neurological Assessment, from the Portuguese *Avaliação Neurológica Simplificada digital*), a mobile health application designed to support standardized neurological evaluation, improve documentation, and enhance longitudinal monitoring in leprosy care. **Methods:** The development of ANSd application was conducted as action research, applying Soft Systems Methodology (SSM) through iterative learning cycles with the Global Partnership for Zero Leprosy (GPZL) digital health priorities. The process included domain and requirement modeling, data model design, interface design, and software implementation. **Results:** ANSd enables digital recording of sensory and motor testing results, aggregates physical disability grading (from Portuguese, *Grau de Incapacidade Física* - GIF) and the Eye-Hand-Foot (EHF) score, and stores structured records to support longitudinal patient follow-up. The ANSd application runs entirely offline through an offline-first architecture with encrypted on-device storage, and reproduces the official ANS form as a populated PDF, preserving regulatory compliance while enabling structured data capture. **Conclusion:** By consolidation standardized clinical data in a single digital platform, ANSd strengthens neurological monitoring and supports early detection of nerve impairment in individuals affected by leprosy. The ANSd application aligns with the GPZL’s strategic vision for digital health and offers a scalable solution for improving disability prevention and data-driven decision-making in leprosy control programs. Within the Brazilian public healthcare system (from Portuguese *Sistema Único de Saúde* - SUS), ANSd has the potential to enhance clinical workflows, facilitate integration with national surveillance platforms, and improve the continuity and quality of care for people affected by leprosy.

Keywords: leprosy, Simplified Neurological Assessment, digital tool, disability prevention

1 Introduction

Leprosy (known as Hansen’s disease in Brazil) remains a significant public health challenge in several low- and middle-income countries, particularly in Brazil, India, and Indonesia. Despite global advances in disease control, the persistence of transmission and the occurrence of physical disabilities associated with late diagnosis highlight the need for more effective strategies for early detection and clinical management [1]. Among the key components of leprosy care, neurological evaluation plays a central

role, as it enables the early identification of peripheral nerve impairment and supports the prevention of irreversible disabilities.

Neurological evaluation in leprosy is a structured clinical procedure performed throughout multiple stages of patient care, including diagnosis, Multidrug Therapy (MDT, from Portuguese Poliquimioterapia-Única - PQT-U), and post-treatment follow-up. This continuous assessment is essential, as nerve damage may occur before diagnosis, progress during treatment, or emerge later due to immunological reactions [2]. The evaluation typically includes sensory, motor, and autonomic assessments of peripheral nerves commonly affected by *Mycobacterium leprae* or *M. lepromatosis*, such as the ulnar, median, fibular (peroneal), posterior tibial, and facial nerves [3]. Sensory testing is conducted using monofilaments or calibrated ethesiometry instruments, while motor function is assessed through muscle strength grading, and nerve palpation is used to detect thickening and inflammation. Additionally, clinicians document deformities and trophic changes, particularly in the hands, feet, and eyes, which may indicate chronic nerve damage [4, 5].

Despite its clinical importance, the consistent implementation and documentation of neurological evaluation remain challenging in endemic regions. In Brazil, the Ministry of Health established the Simplified Neurological Assessment (from Portuguese, *Avaliação Neurológica Simplificada* – ANS) to standardize the evaluation of peripheral nerve function in individuals affected by leprosy. Although the ANS has improved the uniformity of clinical practice, it is still predominantly conducted using paper-based forms. This reliance on analog records introduces several structural and operational limitations, including susceptibility to data loss, physical degradation, incomplete documentation, and transcription errors. Furthermore, the absence of digital integration restricts interoperability across healthcare facilities, limiting longitudinal patient follow-up and reducing the effectiveness of epidemiological surveillance and decision-making processes [6].

In this context, there is a clear need for technological solutions capable of transforming the current paper-based workflow into a structured and integrated digital process. Such transformation is aligned with global initiatives, such as the Global Partnership for Zero Leprosy (GPZL), which emphasizes the role of digital health tools in improving data quality, standardization, and monitoring to support disease elimination efforts [7].

To address these challenges, we present ANSd (Digital Simplified Neurological Assessment, from Portuguese, *Avaliação Neurológica Simplificada digital*), a mobile application designed to digitize the complete ANS workflow at the point of care. The application enables healthcare professionals to perform, record, review, and manage neurological assessments within a structured digital environment, while preserving the official ANS form as the clinical document of reference through automated PDF generation. By organizing data collection, improving record storage, and supporting longitudinal access to previous assessments, ANSd was designed to facilitate patient follow-up and strengthen clinical information management. To ensure applicability in resource-constrained settings, the current standalone version operates entirely offline, with all processing and encrypted data storage performed locally on the mobile device.

An institutional version is also under development to support secure synchronization with a centralized repository whenever network connectivity becomes available, thereby enabling backup, institutional data sharing, and broader longitudinal information management without compromising the application’s offline operation. The system was also designed to run on low-cost mobile devices with limited computational resources.

The application was developed based on ANS forms collected at a reference center for leprosy treatment in Pernambuco, a hyperendemic region in Northeast Brazil. By transitioning from an entirely offline and analog process to a digital platform, this work contributes to bridging the gap between standardized clinical assessment and modern health information systems.

2 Related Work

Digital health solutions for leprosy have been increasingly explored to support clinical management, diagnosis, and data collection processes. Early efforts focused on the development of electronic health record systems, either web-based or mobile, to support notification and monitoring of patients [8, 9]. These systems contributed to improving data organization; however, they were primarily designed for administrative and reporting purposes, with limited support for structured clinical assessment workflows. More recently, mobile solutions such as HansenApp extended this line of work to point-of-care data collection by primary healthcare providers [10], though still without digitizing a standardized assessment instrument. Additionally, institutional initiatives, such as the application developed by the Brazilian Ministry of Health, provide knowledge repositories to assist healthcare professionals in diagnosis and patient management [11].

More recent studies have explored the integration of intelligent techniques into digital tools [12]. A cross-platform application for leprosy screening and classification based on artificial intelligence was proposed in [13], demonstrating the potential of computational models to support early diagnosis.

Beyond these solutions, a variety of digital tools have been proposed with different target users and functionalities. Several applications are designed primarily for frontline healthcare workers, such as AppHans¹, NLR SkinApp (Skin NTDs App)², Rehapp³, Lepra DLS⁴, Separeh⁵, and EfficientSkinDis⁶. Other tools extend their applicability to broader audiences, including patients (e.g., MMRehapp⁷), researchers (e.g., Suspect-RIF⁸), or health systems (e.g., ANS2JSON⁹ and DHIS2). Additional tools include VHans¹⁰, CO2Dnet¹¹, and Evidente¹².

¹<https://app.pandasuite.com/vHAEYsS4?wid=9b7064bd577553ab0019e8>

²https://play.google.com/store/apps/details?id=com.universaldactor.skin_ntds

³<https://play.google.com/store/apps/details?id=org.rehapp.mobile.twa>

⁴<https://play.google.com/store/apps/details?id=org.sbytes.lepralsdls>

⁵<https://orfeu.ppgia.pucpr.br/separeh/system>

⁶<https://github.com/abdulrafay97/EfficientSkinDis/tree/main>

⁷<https://play.google.com/store/apps/details?id=com.mmrehapp.tlmmrehapp>

⁸https://biosig.unimelb.edu.au/suspect_rif/

⁹<https://ans2json.dotlabbrazil.com.br>

¹⁰<https://play.google.com/store/apps/details?id=br.com.vhans&hl=pt-BR>

¹¹<https://github.com/simatec-uis/CO2Dnet>

¹²<https://evidente-tuevis.cs.uni-tuebingen.de>

Mobile-based applications, in particular, have gained relevance due to their potential to support point-of-care activities. Tools such as NLR SkinApp, Rehapp, VHans, and MMRehapp are designed for smartphones and tablets, enabling healthcare professionals to access information, perform assessments, and support clinical decision-making directly in the field. These applications play an important role in improving accessibility, especially in resource-constrained settings. However, their functionalities are often focused on specific tasks, such as diagnostic support, health education, or rehabilitation planning, rather than comprehensive clinical data collection.

From a functional perspective, existing digital tools can be categorized into three main groups: (i) clinical guidance tools, which provide educational and decision support content (e.g., AppHans, Rehapp, MMRehapp); (ii) clinical management tools, which assist in diagnosis, treatment monitoring, or disease progression tracking (e.g., EfficientSkinDis, Skin NTDs App, VHans, ANS2JSON, CO2Dnet and Lepra DLS); and (iii) decision support and data-driven tools, which incorporate predictive models or support large-scale health information systems (e.g., Separeh, Suspect-RIF, DHIS2, and Evidente). While these tools demonstrate the diversity of digital health applications in the leprosy domain, many are not publicly available for download, lack continuous updates, or are limited in terms of integration with existing healthcare workflows.

Despite these advances, an important gap remains in the digitization of standardized clinical assessment instruments for leprosy. In Brazil, the ANS is the primary instrument used for evaluating peripheral nerve function and classifying patients with Hansen’s disease. However, this process is still predominantly paper-based, limiting data accessibility, interoperability, and longitudinal analysis. The closest prior effort, ANS2JSON, addresses part of this gap by converting digitized ANS forms into structured JSON data, but it is primarily an extraction/conversion tool than a point-of-care (PoC) application and does not support the in-field execution, recording, and longitudinal management of the assessment itself.

In this context, the proposed ANSd distinguishes itself from existing solutions by focusing specifically on the digitization of the complete ANS workflow. Unlike other tools that emphasize diagnostic support, education, or isolated clinical functionalities, ANSd enables healthcare professionals to perform, record, and manage neurological assessments directly within a mobile application, while preserving the official ANS form as the regulatory record of reference. By transforming a traditionally offline and fragmented process into a structured digital system, ANSd aims to enhance data quality, portability, and continuity of care, while also enabling the generation of standardized datasets to support clinical management and future analytical applications.

3 Methodology

3.1 Problematization

The Brazilian public healthcare system (from Portuguese, *Sistema Único de Saúde* - SUS) adopts the ANS (see Figure 1) as the national standardized instrument for evaluating peripheral nerve impairment in individuals affected by leprosy, following the

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AValiação Neurológica Simplificada – ANS

Sem: _____

Nome: _____ Idade: _____ Sexo: ☐ F ☐ M

Residência atual: _____ Data Nasc: ____/____/____

Município: _____ UF: _____

Forma Clínica: ☐ T ☐ D ☐ V ☐ N ☐ NC ☐ Classificação Operacional: ☐ PI ☐ MB ☐ Falcilar

Data Início PQT-U: ____/____/____

Legenda: 1 = Indeterminada T = Tuberculose D = Demência V = Virose Neurol N = Neural NC = Não Classificada

FACE	D	E	D	E	D	E	D	E
NARIZ								
Quedas								
Recaimento	(N)							
Perfuração de legado	(N)							
Quedas								
Diminuição da sensibilidade das córneas	(N)							
Logofúrio	(Peda)							
Fechado olho com força	"ma" (N)							
Diminuição da força muscular da palpebra superior	(N)							
Tilgustação	(N)							
Emprego	(N)							
Acuidade cênica central	(N)							
Acuidade visual	(N)							

Legenda: 1 (N) = Não Falcilar indica logofúrio (parar o olho se houver falcilar) 0 (N) = não foi feita

Acuidade visual: utilize "Tabelas de Optico" 1" - disculsa 3" - normal. Se não houver para tempo, usar falcilar e exame. Na ausência de dados, realizar o exame e registrar "ausência de dados no momento da avaliação".

MEMBROS SUPERIORES	D	E	D	E	D	E	D	E
PALEIAÇÃO DE NEUVOS								
Rafal								
Uter								
Mediano								

AValiação de FORÇA	Legenda: Normal = N	Espeçada = E	Dor = D	Choque = C	D	E	D	E
Extensor do punho (ver o punho, braço estendido)								
Flexor do 3º dedo / Abor dedo mínimo (braço estendido)								
Abdução coto do polegar / Flexor do polegar (braço estendido)								

INPECÇÃO E AVALIAÇÃO LINGUAL	3 = Movimento completo	2 = Movimento Parcial	1 = Contrção	0 = Paralizado	D	E	D	E
Legenda: Avaliação Sensorial: Seguir as cores dos movimentos conforme instruções do fabricante.								
0 - círculo fora da palma da mão indica a avaliação do região dorsal entre o polegar e o anel, internado pelo falcilar.								
Inspeção: Garra normal = M. Garra rígida = R. Reabertura = L. Lesões falcilares / Lesões traumáticas = L.								

ACADIOS	D	E	D	E	D	E	D	E
Legenda: Avaliação Sensorial: Seguir as cores dos movimentos conforme instruções do fabricante.								
0 - círculo fora da palma da mão indica a avaliação do região dorsal entre o polegar e o anel, internado pelo falcilar.								
Inspeção: Garra normal = M. Garra rígida = R. Reabertura = L. Lesões falcilares / Lesões traumáticas = L.								

MEMBROS INFERIORES	3ª	2ª	1ª	3ª	2ª	1ª	3ª	2ª	1ª
Quedas									
PALEIAÇÃO DE NEUVOS									
Falcilar									
Total									

AValiação de FORÇA	Legenda: Normal = N	Espeçada = E	Dor = D	Choque = C	D	E	D	E
Extensor do punho (ver o punho, braço est								

Although the ANS standardizes clinical evaluation nationwide, its routine implementation remains predominantly paper-based. Consequently, the benefits of a standardized clinical protocol are constrained by analog documentation workflows, in which information is manually recorded, archived, and retrieved. Paper-based records are inherently susceptible to incomplete documentation, transcription errors, illegibility, physical deterioration, and loss of information, limiting both continuity of care and longitudinal patient follow-up. Furthermore, the absence of structured digital records prevents the efficient reuse of clinical information for epidemiological surveillance, healthcare management, and clinical research.

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contextual validity, and timeliness directly influence the reliability of clinical decision-making and secondary data use [16]. In low- and middle-income settings, digital health technologies have demonstrated considerable potential to improve data quality and strengthen point-of-care workflows by integrating structured information directly into routine clinical practice [17].

Therefore, the research problem addressed in this work is not the redesign of the neurological assessment itself, but rather the digital transformation of an already standardized clinical workflow. The challenge lies in converting the official ANS form into a structured digital infrastructure while preserving its regulatory compliance, clinical semantics, and adherence to existing healthcare practices. ANSd was developed to address this gap by providing a mobile, offline-first solution capable of supporting standardized neurological assessment, secure data storage, longitudinal patient monitoring, and improved information management without modifying the original clinical protocol.

3.2 Soft Systems Methodology (SSM)

Considering the sociotechnical complexity involved in digitizing the ANS workflow within routine leprosy care, this study adopted an action research approach [18]. As a post-positivist research methodology, action research acknowledges the dynamic, context-dependent, and human-centered nature of complex systems, avoiding the reductionist assumptions that often fail to capture the realities of large-scale public healthcare environments.

Within this methodological framework, the method adopted is Soft Systems Methodology (SSM), developed by Peter Checkland [19]. SSM is particularly well suited to addressing ill-structured and socially complex problems, as it facilitates the exploration of multiple stakeholder perspectives, supports organizational learning, and promotes iterative interventions aimed at improving real-world situations rather than identifying a single optimal solution. SSM proceeds through an iterative cycle: identifying the problem situation, expressing it as a rich picture, formulating root definitions of relevant systems and their CATWOE (Customers, Actors, Transformation process, Worldview, Owners, and Environmental constraints), building conceptual models, comparing those models against the perceived real-world situation, and defining feasible and desirable changes. In this work, the rich picture in Figure 2 expresses the problem situation, and the subsequent learning cycles, reported in Section 4, operationalize the comparison and change stages through the iterative design, implementation, and refinement of ANSd.

The research comprehends five learning cycles from Nov, 2024 to June, 2026. The study was conducted with the Otávio de Freitas Hospital (HOF), a state reference unit for leprosy treatment in Pernambuco, as the principal stakeholder, and was approved by the institutional research ethics committee (CAAE: 79763024.8.0000.5192). All interviews were conducted in Portuguese and quotations presented in this manuscript were translated into English by the authors.

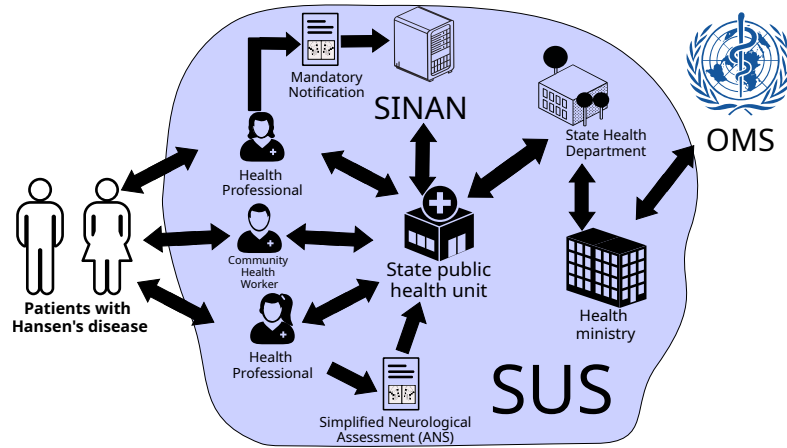


Fig. 2: Domain Rich picture. It illustrates the leprosy care ecosystem, its key stakeholders, and information flows within the Brazilian SUS.

4 ANSd Learning Cycles

4.1 First Learning Cycle

Root Definition: Develop an application that facilitates data sharing between healthcare professionals and patients.

CATWOE Analysis

- **Customers:** Patients receiving leprosy treatment at HOF.
- **Actors:** Healthcare professionals and patients undergoing leprosy treatment.
- **Transformation Process:** Develop a structured data entry framework that enhances data sharing between healthcare professionals and patients.
- **Worldview (Weltanschauung):** Improve the healthcare system without requiring redesign of existing clinical processes while minimizing the need for user training.
- **Owners:** HOF management.
- **Environmental Constraints:** Compliance with the established PCDT Hanseníase.

During this first learning cycle, data storage models were designed, and the paper-based ANS assessment form was translated into a navigable digital interface. One of the main challenges concerned the representation of hand and foot sensory assessments. These evaluations are based on specific anatomical points and include unstructured positional information relative to different regions of the hand or foot. Healthcare professionals typically complete this section of the assessment form in a flexible manner according to each patient's clinical condition. Consequently, these data could not be adequately represented using a simple tabular structure, requiring the development of a representation capable of supporting both variability and flexibility in notation.

The evaluation took place during the development team’s first on-site visit to the hospital. The occupational therapist responsible for conducting the assessments responded positively to the proposed interface model (a high-fidelity prototype). While navigating the high-fidelity prototype, the therapist suggested several improvements to the digital data entry process based on her experience with the paper-based form.

A further issue identified during this cycle concerned the patient-facing version of the system. The socioeconomic conditions of patients receiving treatment vary considerably, including differences in access to digital technologies and services. Consequently, widespread adoption of a patient-oriented digital interface was not considered feasible for a substantial proportion of the target population, particularly for patients traveling from rural and remote municipalities to receive care at the state capital’s referral hospital.

Regarding the notation format, the stakeholder emphasized that data entry should strictly adhere to the PCDT Hanseníase [20]. Although the colors of the monofilaments were consistently represented in the application, the notation itself should replicate the format used in the paper-based assessment form. Maintaining consistency with the standardized documentation was considered essential to preserve clinical familiarity, facilitate interpretation by healthcare professionals, and ensure alignment with established clinical practice.

Following the validation of the proposed model and the recommendations for refinement provided during this evaluation, we proceeded to the second SSM learning cycle.

4.2 Second Learning Cycle

Root Definition: Develop an application that facilitates data sharing between healthcare professionals using mobile phones.

CATWOE Analysis

- **Customers:** Patients receiving leprosy treatment at HOF.
- **Actors:** Healthcare professionals.
- **Transformation Process:** Develop a structured data entry framework that improves data sharing between healthcare professionals.
- **Worldview (Weltanschauung):** Improve the healthcare system without requiring redesign of existing clinical processes while minimizing the need for user training.
- **Owners:** HOF management.
- **Environmental Constraints:** Compliance with the established PCDT Hanseníase.

The second learning cycle focused on refining the prototype developed during the previous cycle and transforming it into a functional prototype for Android devices. Based on observations from the first-cycle evaluation, the research team identified the requirements of primary healthcare professionals within their actual context of use. In addition, discussions with stakeholders indicated that a patient-facing version of the application would have limited practical applicability. Many patients either do not own mobile devices or face barriers related to the use of digital technologies and the

interpretation of information contained in the ANS form. As a result of the iterative design process, this feature was not retained in the ANSd.

Consequently, development efforts were prioritized toward enhancing the digital application for healthcare professionals, with the intention of addressing patient-oriented strategies in subsequent iterations. This decision reflected the understanding that strengthening professional support would provide greater immediate value to the clinical workflow while establishing a foundation for future patient engagement. To support this objective, the database schema was refined to enable an accurate representation of all clinical data. The visual representation of the sensory assessments of the hands and feet was revised to conform to the official notation used in the paper-based assessment form, ensuring consistency with the PCDT Hanseníase and with the established documentation practices of clinicians.

The complete workflow was then implemented as a functional Android application using the React Native framework. This technology was selected because of its cross-platform capabilities and ease of portability, allowing the solution to be more readily adapted for deployment on different devices and operating environments in future development cycles.

In addition, interactions with the stakeholder revealed an important limitation of the ANS form. Although the form is comprehensive, it does not accommodate all clinically relevant data of the treatment. For example, throughout the entire course of treatment, the form provides space only to record the initiation and completion of MDT. However, observations from primary healthcare practice indicated that this structure does not adequately reflect many clinical situations, particularly for patients undergoing prolonged treatment or experiencing leprosy reactions. In these cases, patients may have already completed the formal leprosy treatment and been discharged from MDT, while continuing to receive additional pharmacological interventions or non-pharmacological treatments that cannot be systematically documented within the standard ANS form. As a result, the digital version was extended with a dedicated section to record any treatment or clinical recommendation prescribed during the evaluation of the patient. This section of the application supports documentation of wound treatment, medications administered beyond MDT, referrals to other healthcare professionals, and other follow-up recommendations. In the paper-based workflow, such information was typically recorded informally in the margins or footer of the ANS form. The digital implementation formalized these records, providing a structured and persistent mechanism for documenting the patient's ongoing clinical management while preserving compatibility with existing clinical workflows.

The results from the second learning cycle was positively evaluated by the stakeholder. Overall, the feedback focused on refinements to the ANS data entry workflow, particularly regarding fields that required free-text input rather than predefined selections. Entering text in the application involved opening the on-screen keyboard, completing the field, dismissing the keyboard, and then navigating to the next field. This interaction sequence was not considered intuitive by the stakeholder and was identified as an area requiring usability improvements.

The stakeholder also emphasized the continued importance of the paper-based ANS form as an official clinical record that is readily accessible and easily shared among

healthcare professionals within the healthcare unit. Rather than replacing the existing documentation process, the digital solution should complement established practices while minimizing disruption to clinical workflows.

Finally, the evaluation highlighted a broader contextual challenge associated with leprosy as a neglected disease. Limited information technology infrastructure across many healthcare settings restricts the feasibility of relying on centralized digital systems. Consequently, the stakeholder recommended that the application should maximize the autonomy of individual healthcare professionals by enabling them to register patients and maintain clinical records independently, reducing dependence on continuous network connectivity or institutional information systems. This recommendation informed the direction of the subsequent learning cycle by reinforcing the need for a resilient, decentralized solution capable of operating within resource-constrained healthcare environments.

4.3 Third Learning Cycle

Root Definition: Develop a standalone application that facilitates data sharing between healthcare professionals using mobile phones.

CATWOE Analysis

- **Customers:** Patients receiving leprosy treatment at HOF.
- **Actors:** Healthcare professionals.
- **Transformation Process:** Develop a standalone structured data entry framework that improves data sharing between healthcare professionals without reliance on macro structural change.
- **Worldview (Weltanschauung):** Improve the healthcare system without requiring redesign of existing clinical processes while minimizing the need for user training.
- **Owners:** Health professionals.
- **Environmental Constraints:** Compliance with the established PCDT Hanseníase.

The principal contribution of the third learning cycle was the development of a transformation process capable of converting digitally recorded ANS data into a facsimile PDF version of the official paper-based assessment form. This functionality enabled the application to serve as a digital documentation tool, eliminating the need for printed forms and the colored annotations tools traditionally required to complete the ANS according to the national clinical protocol.

An initial challenge concerned the design of the original paper form itself. Although intended for manual completion, many fields are neither symmetrical nor uniformly sized, making direct automated population impractical. Consequently, the form layout had to be carefully adapted to support accurate automated rendering while preserving the appearance and structure of the official document.

Transforming structured database records into a printable paper representation solved one problem while introducing another interface challenge. Depending on the version, the official paper form accommodates either three or four neurological assessments for the same patient. In contrast, the digital application allows an unlimited

number of assessments to be recorded over time. Therefore, an intermediate mechanism was required to map the digital records onto the constraints of the printable form. Healthcare professionals needed flexibility in selecting which assessments should appear in each generated document. For example, the system should allow users to print the earliest assessments for longitudinal comparison, choose any subset of evaluations that fits within a single form, or generate multiple forms to include the patient's complete assessment history. Supporting these alternative workflows represented a significant implementation challenge, which was successfully addressed during this learning cycle.

The evaluation of this cycle was conducted by digitizing actual ANS forms collected from the referral hospital. The primary objective was to determine whether the proposed workflow was suitable for routine use in primary healthcare and whether all information contained in the paper records could be accurately represented in digital form. During the digitization process, however, it became evident that several data elements could not be directly transcribed because they had been omitted during completion of the original paper forms.

This finding reinforced an important design consideration identified in previous learning cycles. Conventional digital forms typically impose stricter validation rules and encourage completion of mandatory fields. However, in the context of leprosy assessment, certain fields are intentionally left blank for legitimate clinical reasons, most commonly when lesions or other localized conditions prevent the examination of a specific limb or body region. Accordingly, the digital system needs to be designed to permit missing values in selected fields while preserving data integrity and accurately reflecting real-world clinical practice. This adaptation will ensure that the application supported, rather than constrained, the clinical decision-making processes of healthcare professionals.

4.4 Fourth Learning Cycle

Root Definition: Develop a standalone application that facilitates data sharing between healthcare professionals using mobile phones and tablets.

CATWOE Analysis

- **Customers:** Patients receiving leprosy treatment at HOF.
- **Actors:** Healthcare professionals.
- **Transformation Process:** Develop a structured data entry framework that improves data sharing between healthcare professionals.
- **Worldview (Weltanschauung):** Improve the healthcare system without requiring redesign of existing clinical processes while minimizing the need for user training.
- **Owners:** HOF management.
- **Environmental Constraints:** Compliance with the established PCDT Hanseníase.

The fourth cycle began with a change triggered by an external factor. The ANS form was revised to comply with the new version established by the PCDT. The updated form consolidated several variables, introduced new data fields, and reduced

the number of assessments recorded on each form from four to three. Once the research team became aware of these updates, stakeholders were consulted to understand the expected integration curve within routine primary health care practice. At the HOF, the adoption was immediate, and the new form had already become the standard for newly admitted patients. Consequently, development efforts prioritized updating the data models and implementing PDF generation according to the newest and updated form layout.

Subsequently, strategies were implemented to allow selected fields to be recorded as not possible to assess. This modification affected both the user interface and the underlying data model. A new visual element was introduced to indicate that a measurement could not be obtained while simultaneously disabling the previous data-entry interface for those fields. In addition, new database data types were incorporated to explicitly distinguish these records from missing or erroneous values, enabling them to be treated as a valid analytical category in subsequent analyses. The user interface was also adapted to support tablet devices while preserving the same visual organization and interaction flow adopted in the smartphone version.

The evaluation of this cycle was conducted through an extended stakeholder meeting involving primary health care professionals, hospital management, a representative of the State Health Secretariat, and representatives of civil society organizations. The main objective was to present the ANSd to all stakeholders involved in the delivery of leprosy care across the state of Pernambuco. Following the researchers' presentation, an open discussion was held to gather feedback from participants. Representatives of civil society organizations raised questions regarding data protection, governance, and information management. Particular emphasis was placed on the requirement that devices used to store patient assessments should be institutionally managed rather than the personal devices of health professionals. This concern was motivated not only by data governance and security considerations but also by the high vulnerability of personal mobile devices to theft within the local urban context.

The representative of the State Health Secretariat expressed support for the developed solution and indicated the Secretariat's willingness to collaborate in its implementation across health care units, including the possibility of extending its adoption beyond the HOF. The Secretariat also suggested the development of an architectural layer capable of supporting reporting functionalities and analytical tools, such as business intelligence dashboards. Finally, the hospital management reaffirmed its institutional partnership and commitment to supporting both the implementation process and the organizational changes required for successful adoption.

4.5 Fifth Learning Cycle

Root Definition: Develop an integrated application that facilitates data sharing among healthcare professionals through mobile phones and tablets while providing an institutional data repository for secure storage and management.

CATWOE Analysis

- **Customers:** Patients receiving leprosy care at HOF.

- **Actors:** Healthcare professionals.
- **Transformation Process:** Develop a structured framework for data collection, storage, sharing, and analytics that enhances collaboration among healthcare professionals and supports management-level decision-making.
- **Worldview (Weltanschauung):** Improve healthcare delivery without requiring substantial changes to established clinical workflows while minimizing the need for user training.
- **Owners:** HOF management and the State Health Secretariat.
- **Environmental Constraints:** Compliance with the PCDT Hanseníase and the implementation of robust data protection mechanisms to ensure data security and patient privacy.

The fifth learning cycle began with a strategic shift in the administrative direction of the solution. In addition to the standalone version, the development of an institutional version was initiated, incorporating centralized data management and institutional data sharing capabilities. The fundamental security requirements identified during the evaluation of the fourth learning cycle had already been implemented at the individual application level through strong encryption, password-protected access, and the security mechanisms provided by the mobile operating system. However, the introduction of an institutional management system required that all inter-institutional data exchange should maintain the same level of security and privacy guarantees. Despite this new institutional layer, the standalone mode was preserved to ensure that the solution could continue to be adopted in contexts where institutional support or infrastructure is unavailable.

Drawing upon the researchers' previous experience, the architecture was designed to operate either locally or remotely while maintaining the smallest possible computational footprint, thereby minimizing information technology infrastructure requirements. At the same time, the architecture was conceived to support replication and expansion to environments with greater computational resources without compromising scalability. This design decision considered the heterogeneous technological capacities across municipalities within the state, where some local health systems possess substantially fewer resources than others. Consequently, the proposed solution can support both resource-constrained municipalities, particularly those in rural areas, and larger urban health centers. To maximize interoperability and long-term sustainability, the system architecture was designed to avoid vendor lock-in whenever possible.

The resulting architecture consists of a Node.js front-end, a PostgreSQL database repository, and a Java-based API deployed within a Docker container. The containerized architecture enables deployment either on local machines with minimal resource requirements or on scalable cloud-based virtual infrastructures, depending on institutional needs. In addition, a new administrative user role was introduced. This administrator is responsible for managing the encryption keys associated with the distributed databases within each healthcare unit and for registering healthcare professionals as system users. However, this role does not have access to patient assessment records within the ANSd. Instead, its primary responsibility is to manage the

deployment, configuration, and distribution of the application throughout the primary healthcare network. Consequently, the information technology department of each healthcare institution assumes responsibility for the governance of assessment data and user accounts, implementing data management policies according to the institution’s security and privacy requirements.

At the time of writing, this learning cycle remains under development and has not yet undergone stakeholder evaluation. The following section presents the structured results derived from the learning cycles. The reported findings correspond to the most recent versions of the artifacts and processes that have been validated by stakeholders throughout the completed learning cycles.

5 Results

5.1 Data Modeling

The proposed data modeling aims to abstract all information contained in the ANS form (as presented previously in Figure 1) into a structured digital representation within ANSd. Beyond a direct transformation of the paper-based form, the modeling process also considers the contextual needs of healthcare professionals during data entry and retrieval. Manual completion of ANS forms often leads to inconsistencies, illegible entries, limited space for annotations, and even loss of records, compromising data quality and continuity of care. In this sense, the ANSd data model was designed to ensure consistency, integrity, and accessibility, while enabling efficient query operations tailored to clinical workflows.

Figure 3 presents the Entity-Relationship (ER) diagram designed for ANSd, while the complete data dictionary, including the description, English translation, and data type of each database table and attribute, is provided in the Supplementary Material. The model consists of 18 entities, of which seven are reference tables that enforce the integrity of predefined fields. The overall modeling can be conceptually divided into three groups: *(i)* entities related to patient identification, *(ii)* entities related to clinical data, and *(iii)* entities related to graphical data.

The first group encompasses patient identification, treatment records, and healthcare professional information. The *avaliacao* (assessment) entity is the central component of the model, establishing relationships with all other entities and representing each completed ANS form.

The second group includes entities responsible for storing clinical data associated with different anatomical regions affected by leprosy. The *lado* (side) entity plays a key role in this group, as all evaluations must be recorded separately for the right and left sides of the body, particularly for structures such as the face, upper limbs, and lower limbs.

The third group is dedicated to the storage of graphical and semi-structured data collected during the assessment. Entities such as *avaliacao sensitiva* (sensory assessment) and *avaliacao inspecao membro* (limb inspection) assessment represent some of the most complex aspects of the digitization process, as they involve translating

overview screen, where three actions are available: managing treatments, creating a new ANS assessment, or visualizing existing records.

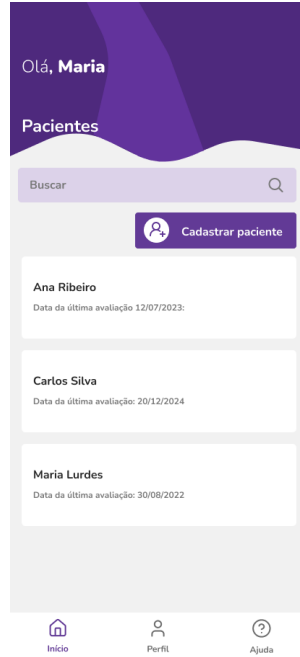
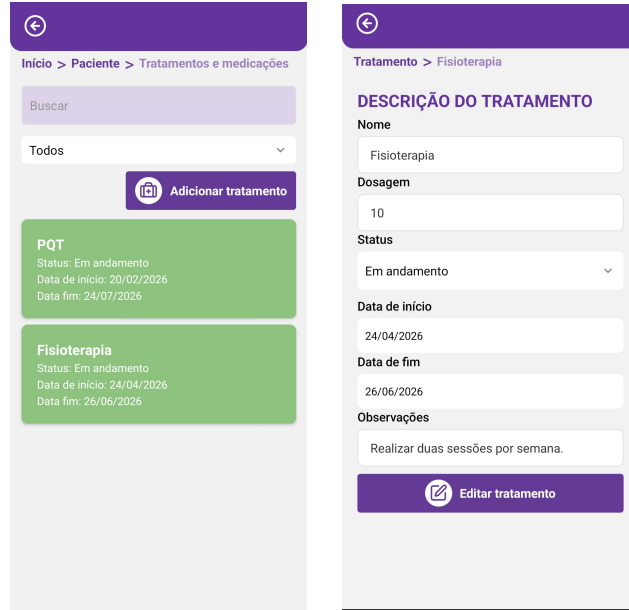


Fig. 4: Initial screen of the application. The screen displays the list of registered patients, each associated with the date of their last assessment, along with a search field and a button to access the patient registration interface.

Figure 5 presents the treatment workflow, which was introduced as an enhancement over the original paper-based form. This module allows healthcare professionals to record and manage both pharmacological and non-pharmacological treatments. A predefined drop-down menu standardizes treatment types, ensuring data consistency. Additionally, users can view detailed treatment information and perform updates when necessary.

The ANS form completion workflow is the most complex component of the system, comprising 14 screens organized into six sections: *(i)* face assessment (nose and eyes), *(ii)* nerve palpation, *(iii)* muscle strength evaluation for upper and lower limbs, *(iv)* sensory assessment of upper limbs, *(v)* sensory assessment of lower limbs, and *(vi)* physical disability grading (from Portuguese, *Grau de Incapacidade Física* - GIF).

Each section follows a structured interface with predefined values to standardize data entry while allowing flexibility when necessary. For instance, facial assessment screens provide predefined complaint options through drop-down menus, while also allowing custom inputs. Similarly, nerve palpation includes standardized options (e.g., normal or thickened, with pain and shock recorded separately), and muscle strength



(a) Treatment list.

(b) Treatment details.

Fig. 5: Treatment management screens. Showing the list of registered current treatments (left) and the detailed view of a treatment record, including status, dosage, dates, and clinical observations (right).

evaluation follows a scale from 0 to 5. These design choices ensure uniformity and reduce variability in data recording.

Sensory assessment represents one of the most complex components of the ANSd application. It can be performed with or without the use of an esthesiometer, with differences reflected in the number of available color-coded responses. As shown in Figure 6, the interface allows healthcare professionals to interactively fill anatomical diagrams (hands and feet) using color markers to represent sensitivity levels. Additional visual markers can also be added to indicate motor impairment. The assessment concludes with the GIF classification screen, where scores for each region (eyes, hands, and feet) are consolidated into two metrics: the GIF classification assigned to the patient (corresponding to the region with the highest value) and the sum of the scores for each region – Eye-Hand-Foot (EHF).

The data visualization workflow provides two functionalities (Figure 7): direct visualization of assessments within the application and generation of a PDF report containing the most recent evaluations. This feature supports information sharing and facilitates integration with existing clinical practices.

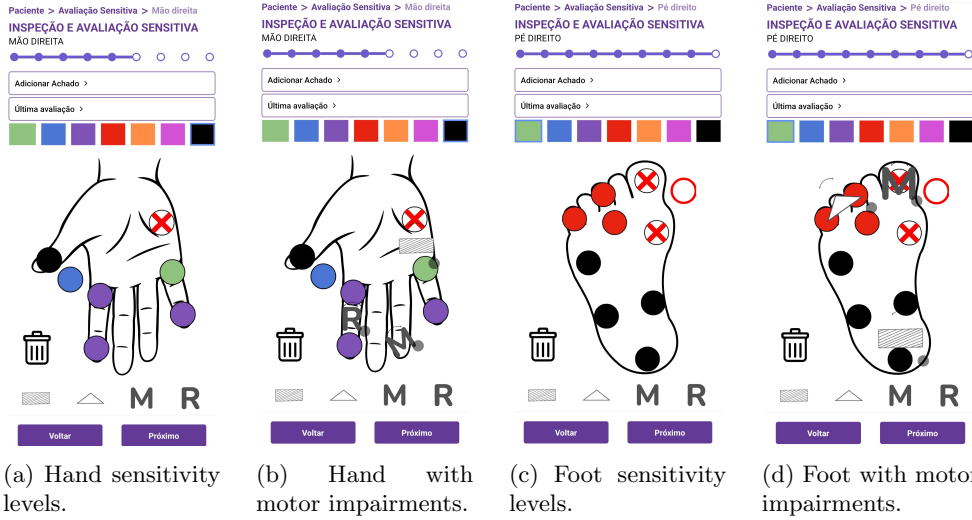


Fig. 6: Sensory assessment screens with clinical markings. Screens of the sensory assessment module, illustrating the recording of tactile sensitivity levels and motor impairments in the hands and feet through standardized clinical markings.

5.3 System Architecture and Implementation

The ANSd application was designed to operate entirely in offline environments, addressing the Brazilian reality of most healthcare facilities with limited or no internet connectivity. To support this requirement, the application adopts an *offline-first* architecture, in which all functionalities are executed locally on the mobile device without relying on external servers or network connectivity.

Within this architecture, backend functionalities are embedded into the front-end, resulting in a self-contained application capable of performing data persistence, business logic, and document generation locally. The system was implemented in TypeScript using the Expo¹³ framework, providing a unified development environment that improves maintainability, portability, and scalability across mobile platforms.

For local data persistence, ANSd employs SQLCipher, an encrypted version of SQLite, accessed through the Expo SQLite driver. This approach provides a lightweight yet robust solution for securely storing sensitive patient information while maintaining high performance for offline operation. The database schema follows the ER model (Figure 3) previously described.

To ensure secure encryption key management, the SQLCipher key is stored using Expo SecureStore, which leverages the native secure credential storage mechanisms provided by Android and iOS. Consequently, even if a device is lost or stolen, the encrypted database remains inaccessible, as the decryption key is released only after successful authentication through the device's native security mechanism, such as

¹³<https://expo.dev/>

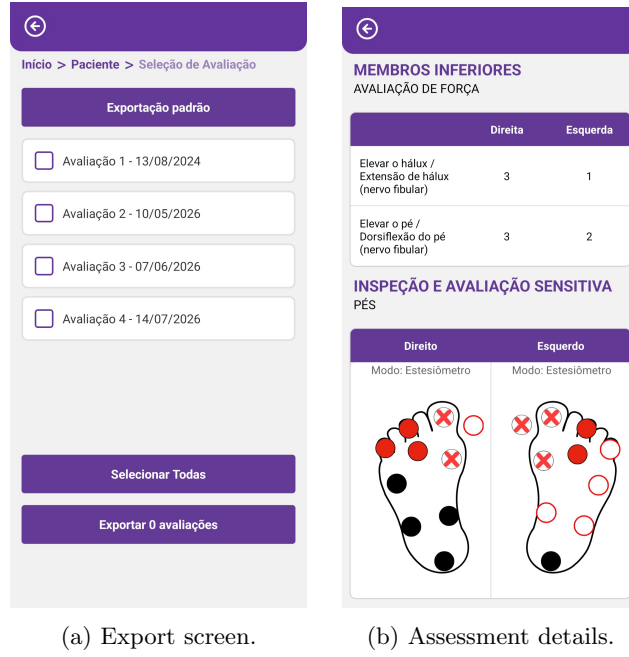


Fig. 7: Data visualization screens. Showing the assessment selection and export screen (left) and the detailed visualization of a recorded assessment (right).

a PIN or biometric verification. This design provides an additional layer of protection for sensitive patient information while preserving the application’s offline-first architecture.

Given the complexity of the database schema, the Drizzle ORM¹⁴ was adopted to simplify database operations. Drizzle translates TypeScript models into SQL queries, reducing development complexity and minimizing implementation errors. Furthermore, it provides automated schema migrations, ensuring database consistency and facilitating future application updates.

5.4 ANS Integration and Data Export

As said, the ANS form is an official document used nationwide in Brazil, and ANSd does not replace it as a formal record. Instead, ANSd provides a mechanism to generate a fully completed version of the original ANS form in PDF format, based on the data stored within the application. This functionality was implemented using a modified version of the ANS form containing AcroForm fields, which allow programmatic data insertion. The PDF is generated using the pdf-lib JavaScript library, enabling the automatic population of all required fields. This approach ensures compatibility with existing regulatory requirements while enabling digital data collection and management.

¹⁴<https://orm.drizzle.team/>

By combining structured data modeling, offline-first architecture, and integration with the official ANS document, ANSd provides a comprehensive solution for modernizing neurological assessment workflows in leprosy care.

5.5 Stakeholder Testimonials

Although a formal qualitative evaluation was outside the scope of this study, stakeholders voluntarily shared their initial impressions after using the ANSd application. The following testimonials are presented solely to illustrate perceived benefits and should not be interpreted as evidence of usability or effectiveness.

Stakeholder testimonial

“The application will streamline my clinical workflow and ensure that patient records are securely stored and well organized.”

— Occupational Therapist, Hospital Otávio de Freitas

Stakeholder testimonial

“The neurological assessment guides clinical decision-making. It helps establish the diagnosis and determine whether the patient started treatment at an early or late stage. It is also an essential tool for monitoring patients throughout their care, particularly for preventing disabilities. Having a digital tool that makes it easier to compare assessments over time improves individual patient evaluation while also enabling surveillance at the population level by identifying the most frequent clinical events. Ultimately, it saves time, improves the quality of care, and provides better outcomes for patients.”

— General Coordinator of Leprosy Surveillance and Diseases Targeted for Elimination, Brazilian Ministry of Health

Stakeholder testimonial

“Without a digitized ANS, we often lose track of the patient and face difficulties in professional training. Digitizing the assessment, and expanding this research, will benefit the health service, academia, researchers, health professionals, and, above all, the patients.”

— State Secretary of Health, Rio de Janeiro

Stakeholder testimonial

“This tool is extremely important for our professionals. The ease of use of the application and the time it saves during consultations are notable. Many cases currently go unassessed at diagnosis simply because of time constraints and high demand. This tool will speed up the process, so that we no longer have so many patients left unassessed.”

— Epidemiological Surveillance of Leprosy, Fortaleza Municipal Health Department

6 Discussion

ANSd addresses a gap that existing leprosy digital health solutions has left open. While the majority of identified existing tools address diagnostic support, health education, or rehabilitation planning, systems for handling clinical records were designed primarily for notification and administrative reporting rather than for supporting standardized assessment. One solution, the ANS2JSON, targets the ANS form but operates as a data conversion tool rather than a point-of-care application. As such, it does not support performing, recording, and longitudinally management the leprosy assessment.

ANSd is, to our knowledge, the first software application to digitize the complete Brazilian ANS workflow at the point-of-care while preserving the official form as the regulatory record of referenced through automated PDF regeneration. This combination is important because ANSd resolves a tension in software adoption in regulated health contexts: structured digital capture and regulatory compatibility. In doing so, ANSd operationalizes the digital health priorities articulated by the GPZL by improving data quality, standardization, and the capacity for monitoring.

The design of ANSd is a direct response to the structural realities of the SUS in Brazil. The fragmentation of responsibility across federal, state and municipal levels, combined with heterogeneous infrastructure and uneven connectivity, makes centralized always-online clinical systems a poor fit for much of the front line on which leprosy care depends. An offline-first architecture that executes entirely on the devices, persists data through on-device encrypted storage, and remains compatible with the official national form, the ANS, is therefore not merely a software engineering convenience but an adaptation to the governance and infrastructure context in which the assessment is actually performed.

The clinical rationale for ANSd follows the established logic of the ANS itself, i.e., consistent, standardized capture of sensory, motor, and palpation findings is a precondition for the early identification of nerve-function impairment that the assessment exists to detect. By reducing the inconsistency, illegibility, and record loss inherent to manual completion, ANSd is designed to raise the quality and continuity of the data on which that detection depends. We are explicit about the boundary of this claim in that the present work establishes the instrument for better data, not improved data or improved clinical outcomes. Whether higher-quality capture translates into earlier

detection, and earlier detection into reduced disability, is a hypothesis that ANSd makes testable rather than a result reported here.

Some limitations qualify these contributions. The benefits described above are grounded in the data model and workflow design rather than in measured performance with end users. The application was developed with a single reference hospital, which constrains generalizability and means that the workflow has not yet been tested across the heterogeneous care models characteristic of SUS. Interoperability with national surveillance infrastructure, such as SINAN, has not been implemented yet.

As future work, we plan to conduct a study involving healthcare professionals and people affected by leprosy to evaluate the usability, acceptability, and effectiveness of ANSd compared with the current paper-based neurological assessment workflow. We will also perform a longitudinal evaluation of the platform to investigate its impact on continuity of care, early detection of nerve function impairment, patient adherence to self-care, and the effectiveness of AI-assisted personalized recommendations delivered through the integrated digital platform.

Ethical approval declarations

This study was conducted in collaboration with Otávio de Freitas Hospital, a state reference center for leprosy care in Pernambuco, Brazil. The research protocol was approved by the institutional Research Ethics Committee under CAAE number 79763024.8.0000.5192. All interviews with healthcare professionals were conducted in Portuguese, and the quotations presented in this manuscript were translated into English by the authors while preserving their original meaning and intent.

Data availability

This study focuses on the design and implementation of ANSd and does not report or analyze identifiable patient-level clinical data. All data generated during the evaluation of the application are protected under the approved research ethics protocol.

An anonymized version of the dataset used for the development and testing of ANSd is publicly available through the Mendeley Data repository at: <https://data.mendeley.com/datasets/hjgfkj3tv/1>.

Code availability

The source code of ANSd is not publicly available because it is currently undergoing software registration with the Brazilian National Institute of Industrial Property. Access to the source code may be considered upon reasonable request after completion of the intellectual property protection process.

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Usage of Generative Artificial Intelligence

In accordance with CNPq Ordinance No. 2,664 of March 6, 2026, we declare the use of Generative Artificial Intelligence tools during the preparation of this manuscript exclusively for language editing and translation into English, specifically the free version of ChatGPT. No Artificial Intelligence tool was used for the conception, scientific analysis, interpretation of results, or substantive intellectual content of this manuscript. The authors take full responsibility for the content presented in this work.

Author contributions

C.J.S. and J.V.S. were responsible for the development of the ANSd application and the preparation of the original manuscript. K.H.C.M. and C.M.M. coordinated the development cycles of the application. G.M, E.S.R., S.R.S.N., and C.M.M. designed the data model. D.C.M.S. served as the clinical stakeholder, supporting the adoption and evaluation of the application in the healthcare setting. K.H.C.M., E.S.R., S.R.S.N., C.M.M., R.A.D., H.G.V.A., T.L., and P.T.E. contributed to the writing, critical revision, and editing of the manuscript. P.T.E. conceived and supervised the project. All authors read and approved the final version of the manuscript.

Competing Interests

There are no competing interests to declare.

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Supplementary information.

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Supplementary Files

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