AI-Based Imaging Screening System for Bone Development in Rural Children: An Intervention Framework Integrating the Health Belief Model

WA AN[1], Ying Lin[2], Liuye Fan[2], zhong Wang[2]

[1]School Of Bay Area Innovation, Guangzhou Academy of Fine Arts
[2]School Of Innovation Design, Guangzhou Academy of Fine Arts

Corresponding author: Ying Lin (e-mail: datouuu02@163.com)

ABSTRACT Inadequate health education and limited parental awareness remain major barriers to the early screening and long-term management of postural skeletal disorders among rural children. With the rapid development of electromagnetic imaging, mobile sensing, and intelligent communication technologies, AI-assisted visual screening has become an effective approach for improving accessible healthcare services in resource-constrained environments. Guided by the Health Belief Model (HBM), this study systematically analyzes existing imaging-based posture screening products and identifies deficiencies in behavioral guidance and continuous intervention support. Questionnaire findings indicate that rural caregivers generally accept mobile imaging screening but encounter practical obstacles, including limited time, transportation inconvenience, and insufficient follow-up participation. Based on comparative product analysis and user surveys, a stage-oriented intervention framework integrating computer vision, mobile imaging, and behavioral cognition is proposed to establish a continuous service loop linking screening, awareness enhancement, intervention, and feedback. The framework transforms conventional one-time posture assessment into an integrated health management process by combining visualized risk communication with personalized behavioral guidance. The proposed design not only improves parental health awareness and participation but also enhances the effectiveness of long-term skeletal posture management. Furthermore, it provides a practical reference for intelligent healthcare systems employing electromagnetic imaging, wireless information transmission, and AI-driven visual perception technologies in rural public health applications.

INDEX TERMS computer vision, postural skeletal screening, health belief model, electromagnetic imaging, intelligent health monitoring

I. INTRODUCTION

CHILDHOOD represents the first peak period of postural skeletal development. Abnormal postural development during this stage may lead to permanent spinal deformities, musculoskeletal pain, and impaired physical function in adulthood, making it critically important to conduct regular preliminary screening for childhood postural health [1]. Currently, China has begun to focus on epidemiological data regarding adolescent scoliosis [2]. Epidemiological studies have shown that urban children in China enter puberty approximately one year earlier than their rural counterparts [3]. Furthermore, in some remote areas, the prevalence of post-rickets sequelae among children reaches as high as 28.9% [4]. Consequently, safeguarding the postural skeletal health of rural children has long been a critical issue in urban-rural public health services. This situation is partly linked to the design strategies of children's bone postural screening products. However, the core challenge in ensuring effective skeleta postural screening lies not solely in screening technology, but in parental health cognition biases. These perceptions hinder the translation of screening results into intervention actions.

From an HBM perspective, rural parents face three key challenges: low perceived susceptibility, weak perceived severity, and limited self-efficacy. Existing screening products, focused on technical outputs, fail to address these gaps and remain confined to detection, lacking a continuous intervention framework, which contributes to poor skeletal postural health management outcomes among rural children. Guided by the Health Belief Model, this study proposes an imaging-based service loop to address knowledge gaps among rural parents, promoting a shift from one-time screening to sustained health management.

II. THEORIES AND LOGIC

A. CORE ELEMENTS AND SCENARIO MAPPING OF THE HEALTH BELIEF MODEL (HBM)

The Health Belief Model (HBM), proposed by Rosenstock and revised by Becker and Maiman [5], stands as one of the most influential behavioral theories in public health. Originally developed to explain (preventive) health behaviors [6], its core assumption posits that individuals' health decisions depend on their subjective perceptions of disease risk and the perceived value of interventions. The model comprises six key components: perceived susceptibility, perceived severity, perceived benefits, perceived barriers, cues to action, and self-efficacy.

In the context of rural children's skeletal screening, these six elements of the Health Belief Model align directly with parental cognitive pain points and design solutions (Table 1). This alignment forms the logical foundation for the design strategies developed in this study.

B. DEVELOPMENT OF AN HBM CLOSED-LOOP SERVICE FRAMEWORK BASED ON IMAGE COMPUTING TECHNOLOGY

In recent years, both domestically and internationally, spinal health management has gradually been incorporated into school physical examinations and public health systems, emphasizing the principles of "early identification, early prevention, and continuous monitoring" [7]. Traditional spinal health screening typically follows a linear "test–report–conclude" model, lacking cognitive guidance and intervention feedback, which makes it difficult to achieve behavioral change. To address this issue, this paper introduces the Health Belief Model (HBM) and combines it with mobile imaging and lightweight computer vision techniques to establish context-adapted "screening–awareness–intervention–feedback" continuous intervention system, thereby transforming posture screening results into actionable, family-friendly interventions, rather than pursuing clinical diagnosis.

In terms of implementation, the system leverages computer vision and image processing to integrate the six elements of the HBM. The system consists of four layers: user, data acquisition, computer vision and analysis, decision and cognition layer. Based on recommended image capture, skeletal features are extracted and analyzed using computer vision techniques to support posture risk prompts, not medical diagnoses. The results are further integrated with the Health Belief Model to enable cognitive mapping and decision support, forming a closed-loop process of screening, intervention, and feedback. Through collaboration between families and schools, this process can provide supporting data for further medical examinations and facilitate ongoing posture health management.

This study develops a continuous intervention framework based on the Health Belief Model (HBM). It helps raise caregivers' awareness of potential posture risks, and delivers long-term behavioral guidance via visual results and data feedback. In this way, traditional linear screening is upgraded to a complete, systematic health management model.

III. METHODS

A. RESEARCH DESIGN

Research employs a theory-driven comparative analysis framework, using the Health Belief Model (HBM) as its core to construct a comparison table of HBM dimensions versus product features. We conducted a functional analysis of currently available skeletal imaging screening products and compared them against the HBM dimensions. The objective is to identify the shortcomings of existing products in terms of cognitive guidance and intervention support from the perspective of "alignment with HBM elements," thereby informing the development of subsequent continuous intervention framework.

To enhance the practicality and contextual applicability of the strategy, this study incorporates a questionnaire survey as empirical support to accurately identify the genuine needs, cognitive characteristics, and behavioral barriers of caregivers of rural children. Furthermore, by designing the study around the six dimensions of the Health Belief Model (HBM) and analyzing behavioral patterns through product comparison and on-site needs assessments, a dual-path research paradigm was established, thereby strengthening the framework's reliability and practicality. The specific steps are as follows:

1) The Specific Steps

- Product Selection: Select representative imaging monitoring products and analyze their official website descriptions and feature documentation to facilitate subsequent comparative analysis across various dimensions.
- Feature Extraction: Break down the feature dimensions of HBM elements and product functions to construct a corresponding dimensional analysis table.
- HBM Feature Mapping: Compare product features against the six dimensions of the HBM one-to-one to determine which features are present and which dimensions are missing.
- Survey: A cross-sectional survey will be conducted among primary caregivers of rural children to collect data on posture health cognition, intervention behaviors, barriers to seeking medical care, and acceptance of mobile screening, which will be used to validate the feasibility of the integrated system strategy.

Through a three-tiered analysis and field questionnaire validation, this study identifies key limitations of existing bone posture screening products in cognitive guidance, behavioral intervention, and continuous feedback. Combined with previously identified service gaps in rural set-

TABLE 1. Mapping the Relationship Between HBM Core Elements and Rural Scenarios

HBM	Table Column Head
Perceived Susceptibility	Belief that "bone and joint problems are rare among rural children, so my child won't have them"
Perceived Severity	Belief that "bone and joint problems will resolve on their own and won't affect growth"
Perceived Benefits	Doubt that "interventions like exercise and sleep posture adjustment have limited effects"
Perceived Barriers	Doubt that "interventions like exercise and sleep posture adjustment have limited effects"
Cues to Action	Lack of awareness of the need for continuous intervention reminders and follow-ups
Self-Efficacy	Concern that "they cannot sustain interventions or may perform them incorrectly"

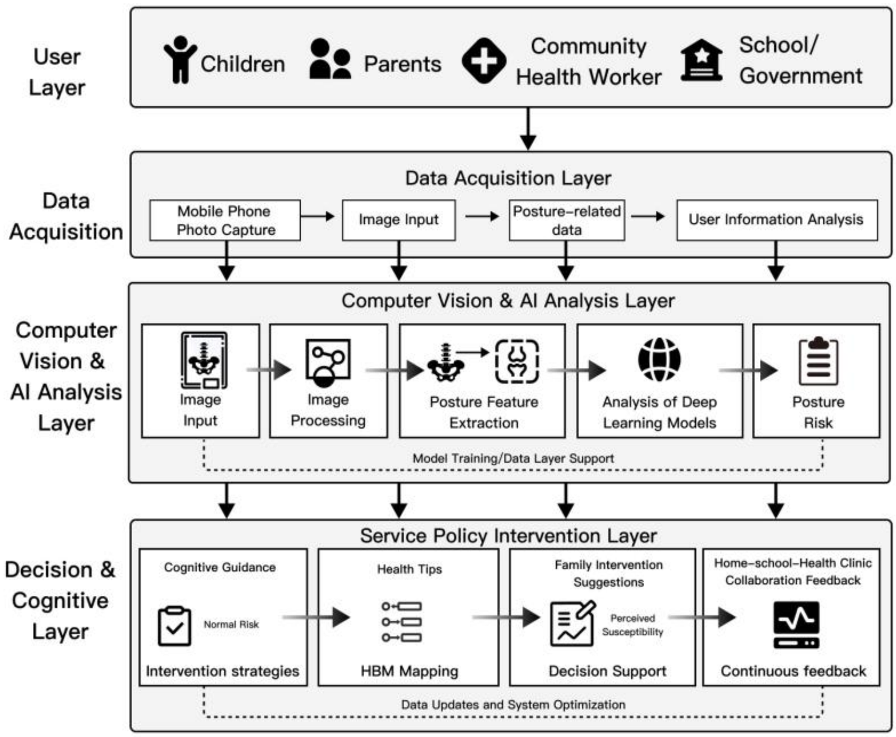

FIGURE 1. System Architecture of Mobile-Based Posture Screening and Management for Rural Children

tings, it develops a continuous intervention framework of "screening–awareness–intervention–feedback."

Grounded in the Health Belief Model, the analysis links rural needs with product functions through framework alignment, feature comparison, and gap identification. This study adopts a theory-driven and demand-oriented approach: the questionnaire part uses descriptive statistics without complex inferential tests. The relevant data, such as frequencies and percentages, were automatically generated by the survey platform and have not undergone inferential testing or quantitative modeling, focusing on extracting genuine needs rather than epidemiological or etiological validation. The findings provide a reliable basis for the context-specific design of an integrated posture screening system for rural children.

IV. EXPERIMENTAL

A. DATA AND MATERIALS

1) Product Analysis

This study conducts a comparative analysis on two types of representative children's skeletal posture screening products. Conducted comparative analysis of two representative products for screening children's skeletal posture: high-precision medical device and a low-cost, single-function screening device. The product samples analyzed in this study were sourced from: representative products available on the market, as well as research prototypes or patented products.

The primary objective is to examine design patterns in existing product features of the Health Belief Model (HBM), identify their key limitations, and derive fundamental design principles from them, drawing on the underlying logic of the feature and applying it to rural contexts through thoughtful consideration, rather than aiming to replicate the full complexity of these systems.

Drawing on existing medical research [16], the study deconstructed the HBM elements and product functional dimensions, resulting in a core HBM element-product function correspondence analysis table (Table 2). This table provides a basis for subsequent product evaluation.

2) User Questionnaire Survey

This study developed a structured questionnaire to explore the needs of caregivers responsible for rural children's posture health management. Grounded in the Health Belief Model (HBM), the questionnaire was organized into four core sections: basic cognition, practical barriers, acceptance of mobile screening tools, and willingness to participate in intervention. The corresponding relationships between questionnaire dimensions and HBM constructs are presented in Table 3. Valid questionnaires were collected from 113 rural parents and primary caregivers.

V. RESULTS AND DISCUSION

A. PRODUCT ANALYSIS

Based on HBM Core Elements and Product Functionality Correspondence Analysis Table (Table 2), an analysis of 10 digital screening products for high-precision medical device (Table 4) High-precision postural assessment devices provide accurate skeletal posture analysis and multidimensional data, but their dependence on specialized equipment and professional operation limits their applicability in rural areas. In contrast, low-cost products tailored for rural settings are affordable and easy to operate (Table 5). However, they can only perform single-indicator testing, and the results are highly subjective. Moreover, they entirely lack mechanisms to underpin HBM-oriented cognition and behavioral change. In summary, current imaging-based screening products can effectively identify postural or skeletal abnormalities through visual outputs such as images, color coding, and angular annotations, thereby helping users identify potential risks. Static result presentation may leave parents without clear follow-up guidance, causing health actions to stop after risk identification. Therefore, existing systems place greater emphasis on anomaly detection, which does not provide continuous health monitoring.

B. USER QUESTIONNAIRE SURVEY

This study collected a total of 113 valid questionnaires completed by the primary caregivers of rural children through a questionnaire survey.

The survey results show that 69.03% of caregivers are aware of posture-related issues in children, but their understanding is largely limited to general health concerns regarding appearance, such as problems with sitting and standing posture. Over 75% of caregivers also believe that poor posture may affect physical development and self-confidence. However, further investigation into intervention measures revealed that 46.9% of parents merely offer a simple verbal reminder when they notice their child's poor posture, and 30.09% of parents remain at the cognitive level, believing that specialized screening is unnecessary. Regarding practical barriers, 56.64% of parents cited time constraints due to work or farming, while 36.28% mentioned inconvenient travel distances. Questionnaire data also indicates that the vast majority of parents hold a positive or cautiously accepting attitude toward mobile imaging screening products. 34.51% of parents indicated they would trust the results and take immediate action, while 51.33% would use them as a reference and seek further professional advice.

76.99% of respondents hoped the system would provide short videos for home-based correction exercises, and 64.6% of parents were willing to supervise their children in completing daily posture training tasks. This indicates that parents place greater emphasis on accessible, sustainable health guidance and support in everyday settings.

C. HBM-GUIDED SCREENING AND INTERVENTION STRATEGIES BASED ON IMAGING TECHNOLOGY

This study adopts the six core components of the Health Belief Model (HBM) as a guiding framework. Integrates product analysis and questionnaire findings to propose a lightweight, integrated AI imaging framework for rural children's postural health. This system is an integrated imaging analysis platform for postural abnormalities. It employs high-precision visual algorithms and utilizes simple mobile devices for data collection. The design maintains the precision of advanced imaging technology while enabling lightweight, easily accessible screening tailored to rural settings.

The system service cycle includes four stages–active screening, health awareness buiding, guided intervention, and follow-up feedback–each aligned with HBM components to form a continuous cycle. The workflow is illustrated in Figure 2.

1) Active Screening

To address limited medical resources in rural areas and parents' low participation in screening, this study proposes a mobile imaging screening station model. The system combines portable posture recognition technology with depth imaging methods to support non-contact data collection and reduce dependence on specialized medical settings. Previous studies have demonstrated shown that computer vision methods can achieve high-precision segmentation of back images and identify spinal features without the need for radiographic imaging, thereby significantly improving the accuracy and scalability of non-invasive screening [8]. These image-based analytical methods help improve access to screening and reduce practical barriers caused by travel distances, insufficient medical resources, and the inconvenience of screening.

The system generates on-site reports that present postural deviations as simplified skeletal images (Figure 3), thereby enhancing users' perceptual sensitivity. By color-coding risk levels, It provides a clear indication of skeletal development affected by potential postural issues. Current research

TABLE 2. HBM Core Elements and Product Functionality Correspondence Analysis Table

HBM	Product Features
Perceived Susceptibility	Whether the product provides functions such as "risk comparison dashboard", "risk classification prompt", and "peer group reference"
Perceived Severity	Whether the product includes content such as "long-term hazard description of posture-related issues", "untreated risk warning", and "practical case validation"
Perceived Benefits	Whether the product presents modules such as "intervention effect prediction", "data comparison before and after intervention", and "successful case demonstration"
Perceived Barriers	Whether the product has features such as "user-friendly operation design", "rural scene adaptation (convenience / low cost)", and "simplified guidance content"
Cues to Action	Whether the product has functions such as "regular review reminders", "intervention progress push notifications", and "data tracking feedback"
Self-Efficacy	Whether the product provides support such as "intervention operation guidelines", "online consultation channels", and "positive feedback incentives"

TABLE 3. Correspondence between Questionnaire Dimensions and HBM Core Constructs

HBM	Questionnaire Dimensions	Specific dimensions
Perceived Susceptibility	Basic cognition	Posture health cognition
Perceived Severity	Basic cognition	Posture health cognition
Perceived Benefits	Practical barriers	Barriers to seeking medical care
Perceived Barriers	Acceptance of mobile screening tools	Acceptance of mobile screening
Cues to Action	Acceptance of mobile screening tools	Acceptance of mobile screening
Self-Efficacy	Willingness to participate in intervention	Intervention willingness

TABLE 4. HBM Core Elements and Product Functionality Correspondence Analysis Table

Product Name	Product Features	Corresponding HBM Constructs	Missing HBM Constructs
Posture-Screen	Posture and angle visualization, body outline overlay	Perceived Susceptibility	Perceived Severity, Perceived Benefits, Self-Efficacy
Pose Pro	Single-Image AI Pose Skeleton Visualization	Perceived Susceptibility	Perceived Benefits, Cues to Action
Posture AI	AI-powered automatic scoring, visual training feedback	Perceived Susceptibility, Self-Efficacy	Perceived Severity
ePose	Visualization of the Plank Posture Report	Perceived Susceptibility	Perceived Benefits, Cues to Action
ScolioScreen App	3D Spinal Curvature Mapping, Postural Trend Analysis	Perceived Severity	Perceived Benefits
SpineScan Mobile	Age-matched Posture Comparison, Risk Level Classification	Perceived Susceptibility, Perceived Severity	Cues to Action, Self-Efficacy
Vicon Motion Capture	3D Gait/Posture Dynamics Visualization	Perceived Susceptibility	Perceived Benefits, Cues to Action
Scolioscan Air	3D Ultrasound Scoliosis Mapping	Perceived Susceptibility	Perceived Benefits, Cues to Action
DIERS 4Dmotion	Dynamic Spine, Pelvis 3D Motion Data	Perceived Severity	Perceived Benefits, Self-Efficacy
PostureRay	X-ray Annotations, Posture Analysis Report	Perceived Susceptibility, Perceived Severity	Cues to Action, Self-Efficacy

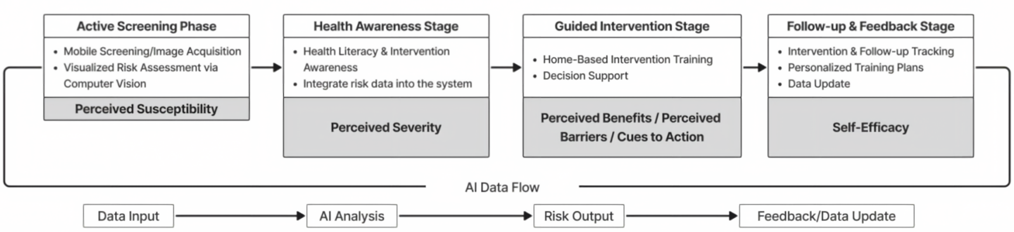

FIGURE 2. A Lightweight AI-Enhanced Framework for Posture Health Screening and Intervention Among Rural Children

demonstrates that AI technology can collect film data to generate normal images [9]. Similar imaging-based educational models have been validated in South Korea's child mental health program for significantly improving parental disease awareness and patient follow-up compliance [11].

2) Health Awareness Building

To address parents' concerns about the underestimation of skeletal issues and the effectiveness of the intervention, a "Structured Cognitive Guidance Module" was designed. Previous studies have shown that computer vision-based

TABLE 5. Functions and Limitations of Simple Screening Tools

Product Name	Product Features	Core Limitations	Supported HBM Constructs	Missing HBM Constructs
Theratools	Spinal curvature measurement	Limited to single screening function; highly susceptible to operator technique.	Perceived Susceptibility	Perceived Severity, Benefits, Self-Efficacy
TsoLay-Electronic Spinal Goniometer	Digital scoliosis measuring instrument	Only single-plane measurement is available; unable to assess three-dimensional deformity.	Perceived Susceptibility	Severity, Benefits, Cues to Action
PostureZone Kidz Grid	High-low shoulder and scoliosis screening	Static assessment; results are significantly affected by shooting angle and lighting conditions.	Perceived Susceptibility	Severity, Self-Efficacy
Efoot320	Foot data acquisition and measurement via standing in the scanning area, including foot arch analysis	Requires power supply; limited to foot-only measurements.	Perceived Susceptibility	Benefits, Cues to Action
Green Earth–Vinyl Floor Mat	Developmental screening, foot valgus/varus detection	Pure manual visual assessment; results are highly subjective.	Perceived Susceptibility	Severity, Benefits, Self-Efficacy
PelmaMotus Lite	Posture and gait detection, with diagnostic reports and recommendations	Dependent on power supply and professional interpretation; complex equipment setup.	Perceived Susceptibility, Perceived Severity	Self-Efficacy, Cues to Action
FONCTI-630	Scoliosis screening and dynamic gait function detection	Requires stable power supply and dedicated space; imposes strict requirements on children's posture and clothing.	Perceived Susceptibility, Severity	Benefits, Self-Efficacy

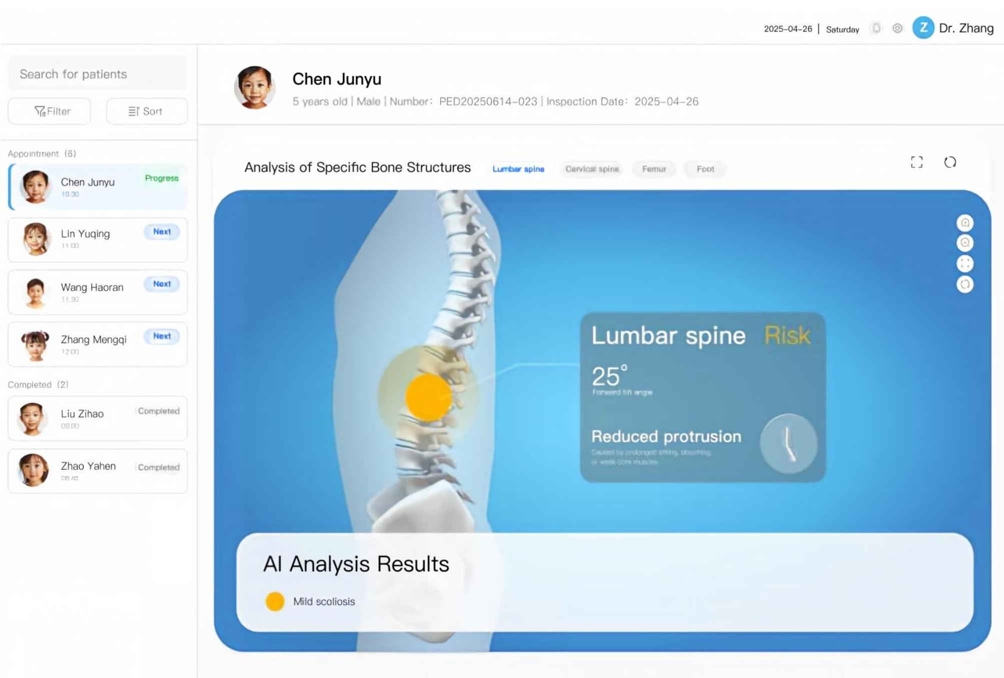

FIGURE 3. The system interface displays a simplified skeletal image

posture recognition and anomaly detection technologies can assist in posture assessment and early risk warning in non-medical settings [12]. Based on existing research, this paper proposes a mobile system that analyses children's posture images to identify posture patterns and trends (Figure 4), Converting the results into visual information that improves parents' understanding and awareness. Cognitive guidance and positive prompts in the digital module aim to increase user engagement and encourage continued participation [13]. When reviewing reports, users can select body regions via touchscreen or mobile app. The system then displays corresponding 3D posture change diagrams with risk level descriptions, such as "mild spinal deviation" or "shoulder-neck stress concentration." It also illustrates the progression from normal spinal alignment to mild scoliosis and its impact on height and posture. This visual presentation reinforces parents' perception of severity through clear visualization. Additionally, the system provides a "projected

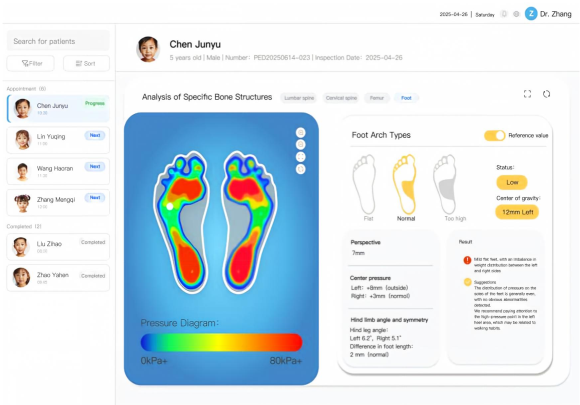

FIGURE 4. Skeletal Analysis Diagram of Specific Areas of the System Interface

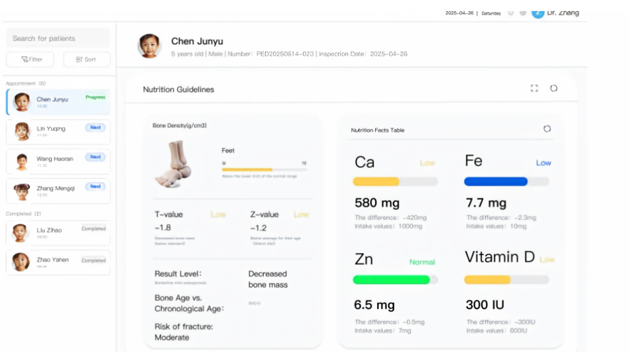

FIGURE 5. Systematic Nutrition Supplementation Recommendations Chart

intervention outcome diagram" after screening, including comparative case examples, thereby enhancing parental confidence in taking subsequent action.

3) Guided Intervention

To address parents' concerns about intervention and implementation, a rural-adapted family intervention model informed by questionnaire findings was developed.while 64.6% were willing to supervise children in daily posture training tasks., Therefore, the system can be designed to provide targeted health education based on the results of posture assessments, covering guidance on posture, sleep, exercise, and nutrition. By encouraging daily healthy habits, the system effectively raises parents' health awareness (Figure 5). This tiered, interactive dissemination approach references the World Health Organization's "Health Literacy Ladder" model [10], which prioritizes knowledge delivery based on behavioral relevance. Supported by computer-based data processing, the system translates screening results into structured, personalized recommendations, aligning identified risks with appropriate interventions. By combining visualized cognitive education with interactive and situational teaching methods, the system enhances behavioral awareness among parents and children. Health knowledge is embedded within daily family interactions, rendering screening outcomes comprehensible and actionable.

4) Follow-Up Feedback

To address parents' limited awareness of sustained intervention and discontinuation. The system pushes "Report on Children's Skeletal Structure and Posture," comparison of data before and after the intervention, automatically reminding parents of follow-up appointments, and providing continuous actionable insights; Quarterly "Intervention Effectiveness Summaries" are generated, recording of skeletal posture development trends through charts and comparing them with data from non-intervened children to reinforce the recognition that "sustained intervention yields results."

Finally, by establishing a Children's Postural Health Database, visual reports on health trends can be generated, including urban-rural comparisons of abnormalities in skeletal and postural development and age- and gender-specific trends. These outputs can inform school health management and regional policy decisions, supporting the sustainable operation of the service loop.

VI. CONCLUSIONS

The core innovation of this study lies in using the Health Belief Model as the logical foundation for guidelines for system design, proposes an intervention design strategy aimed at improving the bone health of rural children.

Given the financial and resource burdens associated with high-tech medical products, the study highlights the need to explore more efficient and accessible screening methods [14]. Therefore, this paper draws only on the computer-based image analysis and feedback mechanisms of these products, with the hope that they can be adapted in the future to platforms better suited to rural settings, thereby improving screening efficiency and service accessibility in rural areas.

By integrating product analysis with survey results, the study developed an educational intervention combining mobile vision screening with ongoing family engagement, thereby bridging theory and practice. The results indicate that this system enhances parents' risk awareness and engagement in the intervention, and promotes sustained behavioral improvement through visual reports and family interaction. Survey data show that most parents support home-based short-video training and daily monitoring, validating the system's feasibility.

Of course, this study has certain limitations: its main conclusions are based on product analysis and lack validation through field interventions. Future research should validate the service integrated system through rural field experiments and quantitatively assess the effects of HBM components, clarifying the relative influence of perceived susceptibility and self-efficacy on parental intervention behaviors to inform design optimization.

Overall, this study combines the Health Belief Model and service design to develop an intervention framework for the rural children's skeletal screening, offering insights for the digital transformation of rural public health services.

AUTHOR CONTRIBUTIONS

Conceptualization – Wa A, Liuye F, Ying L and Zhong W; methodology – Wa A, Ying L; investigation – Wa A and Ying L; resources – Wa A; writing-original draft preparation – Wa A, Ying L; writing-review and editing – Wa A; visualization – Ying L, Liuye F and Zhong W; supervision – Wa A. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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