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Design and evaluation of an intelligent physical examination system in improving the satisfaction of patients with chronic disease

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ABSTRACT

Background: and Purpose: Enhancing patient satisfaction remains crucial for healthcare quality. The utilization of artificial intelligence (AI) in the Internet of Health Things (loHT) can streamline the medical examination process. Most Traditional Chinese Medicine (TCM) examinations are non-invasive and contribute significantly to patient satisfaction. Our aim was to establish an intelligent physical examination system that amalgamates TCM and Western medicine and to conduct a preliminary investigation into its effectiveness in enhancing the satisfaction of patients with chronic diseases.

Materials and methods: Experts from clinical departments, the equipment department, and the software development department were invited to participate in group discussions to determine the design principles and organizational structure of the intelligent physical examination system. This system integrates TCM and Western medicine. We compared the satisfaction levels of patients examined using the intelligent physical examination system with those examined using the traditional medical examination system.

Results: An intelligent physical examination system, combining TCM and Western medicine, was developed. A total of 106 patients were finally enrolled (intelligent group vs. control group) to evaluate satisfaction. There were no statistically significant differences between the intelligent group and the control group in age, gender, education, or income level. We identified significant differences in five aspects of satisfaction: 1) the physical examination environment; 2) the attitude and responsiveness of doctors; 3) the attitude and responsiveness of nurses; 4) the effectiveness of obtaining results; and 5) the information regarding physical examination and medical advice ($p < 0.05$). Furthermore, these differences remained statistically significant even after adjusting for age, gender, education, and income level.

Conclusions: The intelligent physical examination system effectively capitalized on the advantages of combining AI with the integration of TCM and Western medicine, substantially optimizing the medical examination process. In comparison to the traditional physical examination system, the intelligent system significantly enhanced patient satisfaction. Future improvements could involve integrating chronic disease follow-up technology into the system.

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1. Introduction

The doctor-patient relationship stands as a cornerstone of healthcare quality, and the satisfaction of patients profoundly influences this relationship [1–3]. Elevating patient satisfaction holds the potential to positively impact healthcare quality. Nonetheless, patients often encounter prolonged waiting times and cumbersome physical examination procedures during outpatient visits, significantly affecting their satisfaction. Thus, hospitals urgently need to enhance outpatient services by diminishing wait times and optimizing the physical examination process. This endeavor aims to alleviate time and economic burdens on patients, enhance the accessibility of healthcare resources, and ultimately elevate patient satisfaction.

The Internet of Things (IoT) represents an emerging wireless network technology, facilitating object communication over the Internet to establish unified systems [4]. The fusion of IoT with medicine and health, known as the Internet of Health Things (IoHT), enables the utilization of AI to develop intelligent systems in hospitals. These systems aim to enhance patient satisfaction by optimizing outpatient processes and resource allocation [5–9].

Similarly, in line with IoHT advancements, Traditional Chinese Medicine (TCM) has also evolved. Observing tongue conditions, for instance, has progressed from naked eye observation to the quantitative analysis of tongue images. Similarly, the traditional pulse-taking method has transformed into pulse condition acquisition and quantitative analysis [10]. These advancements in TCM not only improve patient satisfaction but also emphasize non-invasive or low-invasive methods for physical examinations. However, there remains a gap in research exploring the impact of combining IoHT with physical examination systems integrating TCM and Western medicine on patient satisfaction.

This article delineates the design and implementation of an intelligent system based on IoHT for the physical examination of chronic disease patients. This system integrates TCM with Western medicine to provide intelligent health services. The Materials and Methods section elaborates on the system's design, application, and evaluation. The Results section presents the principles and structure of the system, along with the effects of its application. Finally, the Discussion section delves into the strengths and limitations of this study.

2. Materials and Methods

The study comprised three phases—design, application, and evaluation—conducted between 2019 and 2021, with approval from the Ethics Committee of Shanghai East Hospital, Tongji University School of Medicine (NO. [2019] 010).

2.1. Design of the system

Experts from various clinical departments, including general practice, nutrition, rehabilitation, and TCM, along with representatives from the equipment and software development departments, participated in group discussions. These deliberations aimed to establish the design principles and organizational structure for the intelligent physical examination system. Additionally, the discussions facilitated the allocation of seasoned technicians and mature software equipment, culminating in the development of an intelligent physical examination system that seamlessly integrated TCM and Western medicine.

2.2. Application and evaluation of the system

2.2.1. Study population

A prospective cohort study was conducted from August 2019 to November 2019, enrolling 115 patients undergoing physical examinations. Of these, 55 were allocated to the intelligent system (intelligent group), while 60 patients were designated to the traditional system (control group). Inclusion criteria comprised individuals aged 18–80 with one or more chronic diseases (e.g., hypertension, diabetes, coronary heart disease, hyperlipidemia), absence of acute health issues, and provision of informed consent. Exclusion criteria encompassed serious primary diseases (e.g., cancer, systemic lupus erythematosus, conditions necessitating major surgery), and unwillingness to provide written informed consent. Basic information of all participants was recorded, and participants had the autonomy to select the questions they wished to answer.

2.2.2. Satisfaction score

Satisfaction questionnaires from patients undergoing physical examinations in both systems were collected, focusing on five key aspects: 1) physical examination environment; 2) attitude and responsiveness of doctors; 3) attitude and responsiveness of nurses; 4) effectiveness in obtaining results; and 5) information pertaining to physical examination and medical advice. Scores ranged from 1 to 5, representing very dissatisfied (1), dissatisfied (2), medium (3), satisfied (4), and very satisfied (5) (**Additional file 1**).

2.2.3. Statistical analysis

Statistical analyses were performed using SPSS22.0 software (IBM SPSS, Armonk, NY, USA). Continuous variables (satisfaction scores) conforming to normal distribution were presented as mean ± standard deviation (SD) and analyzed via student's t-test or Mann-Whitney *U* test. Categorical variables (basic information) were expressed as numbers and percentages and assessed using the Chi-squared test or Fisher's exact test. Furthermore, satisfaction score aspects were categorized into very satisfied (satisfaction score = 5) and non-very satisfied (satisfaction score <5) groups. Binary logistic regression was employed to examine the association between satisfaction scores and the intelligent physical examination system. Parameters with $P < 0.3$ in the prior analysis were included in the multivariable logistic regression. A significance level of $P < 0.05$ was adopted for statistical significance.

3. Results

3.1. Principles of system design

(1) Intelligent principle: Utilization of mature AI instruments and equipment to construct an intelligent physical examination system.
(2) Personalization principle: Development of personalized health management plans for each subject based on TCM characteristics.
(3) Standardization principle: Adherence to relevant industry standards across all system modules and technologies. Health assessment and intervention recommendations align with authoritative guidelines and consensus.
(4) Security principle: Ensuring full data security and confidentiality, limiting data query and analysis access to authorized managers.
(5) Rapid, comprehensive, and low-invasive principles: Complete integration of AI, TCM, and Western medicine advantages to offer more convenient patient services.

3.2. Structure of the system

The outpatient clinic-based intelligent system, depicted in Fig. 1, encompasses a physical examination section and a health advice section. Patients access accurate examination results and comprehensive medical advice swiftly via electronic or paper formats.

The system's primary advantages lie in its speed, comprehensiveness, and non-invasive nature. It comprises both TCM and Western medicine components (Fig. 1), each featuring six examination methods. All data can be transmitted through various devices for cloud computing in big data settings.

4. TCM part

4.1. TCM integration

TCM remains a prominent treatment option in Chinese culture, with a legacy spanning thousands of years. Even today, it holds significance in disease prevention and treatment. The advent of IoT has propelled the establishment of substantial TCM-based big data, facilitating AI's effective integration into TCM practices. Additionally, the non-invasive or low-invasive nature of most TCM examinations enables effective patient health assessments, complementing traditional physical examinations.

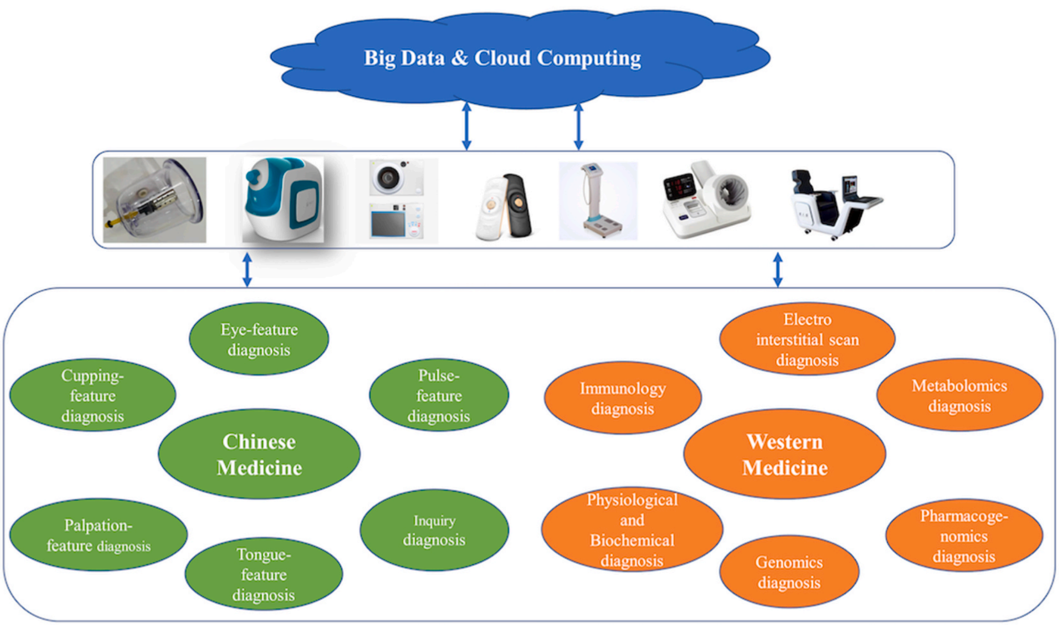


Fig. 1. The structure of the intelligent system.

4.2. TCM examination methods

In the TCM segment of the system, examinations are primarily grounded in the theory of the Yellow Emperor's Inner Canon (Huangdi Neijing), a cornerstone of TCM theory [11]. All examinations in this segment are non-invasive. A TCM practitioner conducts inquiry and palpation examinations, utilizing voice-input equipment to record patient information. Tongue-feature examinations involve capturing two images of the patient's tongue to assess color, size, and coating.

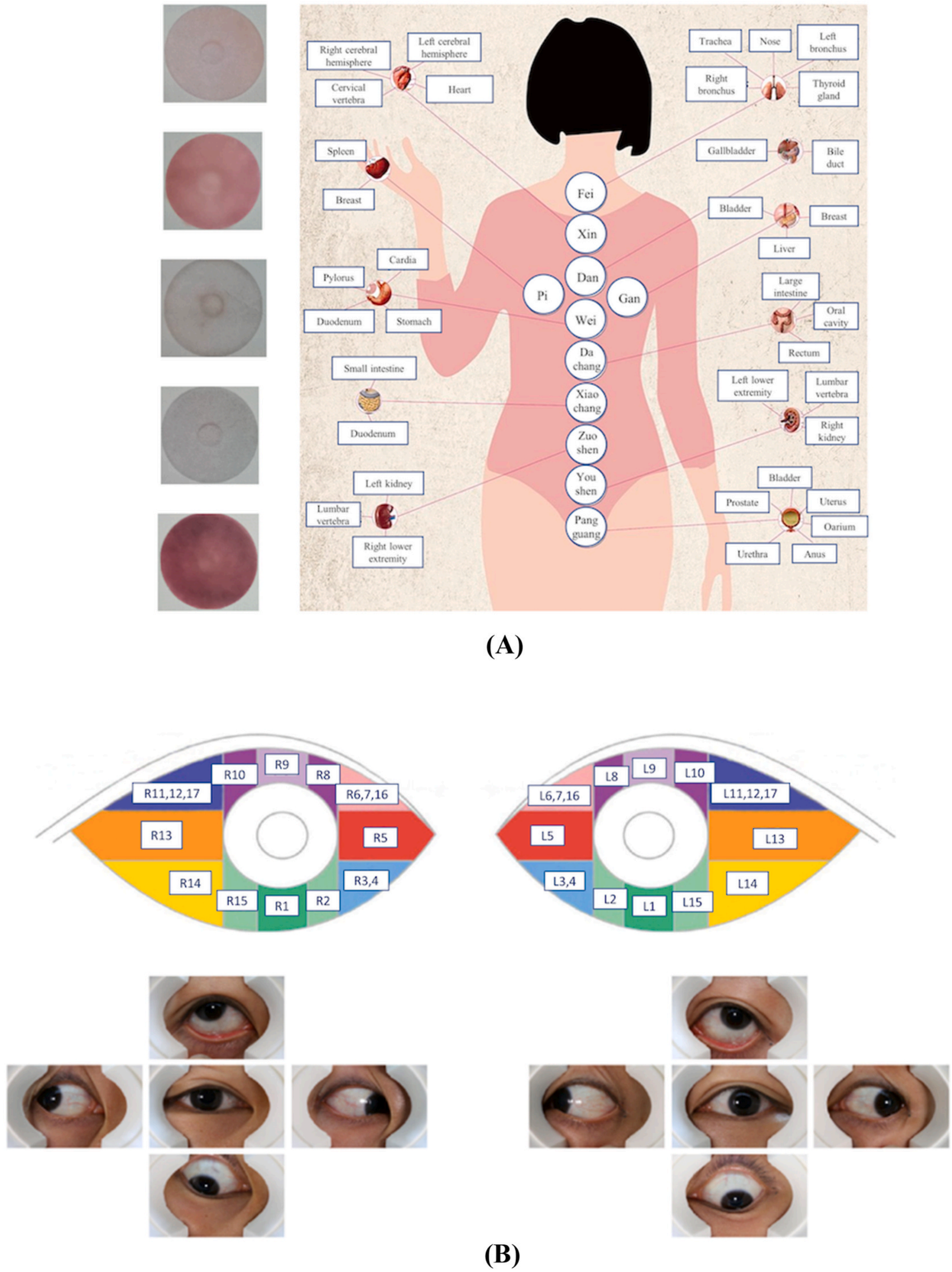


Fig. 2. (A) Cupping features recorded and uploaded by cups
Fig. 2 (B) Schematic diagram of eye-feature and eye-feature images.

4.3. Modernization of TCM examinations

Examining cupping features and eye features exemplifies the modernization of TCM practices. Cupping, a historical therapeutic method in TCM, leaves skin pigmentation at different sites, reflecting patient characteristics [12,13]. In the intelligent system, cupping features are recorded and uploaded via sensor-equipped cups, distinguishing colors and temperatures at specific acupuncture points to gauge organ health (Fig. 2 A).

Eye-feature examination in TCM observes blood vessels, fog, and spots in the eyes, indicative of organ health [14]. The intelligent system employs an advanced imaging method free from illumination source reflection shadows and intricate manipulations for this examination [15]. Ten images of different eye sections assess organ conditions and disease risks (Fig. 2 B).

4.4. Data integration and accessibility

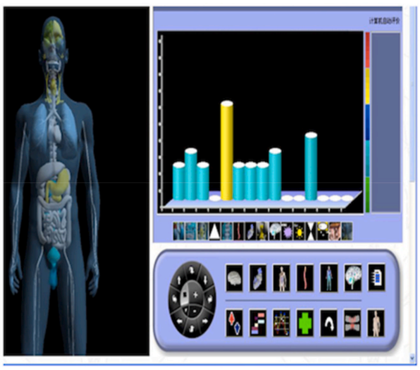
All data from these six examination methods are collated and uploaded to big data for AI cloud computing through IoHT, generating comprehensive medical advice. Remarkably, the entire process takes less than half an hour, with results available within minutes.

5. The Western medicine part

5.1. Integration of Western medicine techniques

The Western medicine segment integrates various diagnostic technologies such as ultrasound, computed tomography, and electrocardiogram, connecting them to the intelligent system. These technologies include advanced diagnostic approaches like

(A)



Parameters	
Biochemical parameters	Triglyceride, glutamic oxaloacetic transaminase, glutamic pyruvic transaminase, alkaline phosphatase, transpeptidase, blood glucose, low density lipoprotein
Electrolyte parameters	Potassium ion, sodium ion, chloride ion, calcium ion, magnesium ion, iron ion, phosphorus ion
Blood gas parameters	carbon dioxide partial pressure, partial pressure of oxygen, residual alkali, pH value, hydrogen ion, bicarbonate ion
Hormone parameters	Thyroid stimulating hormone, follicle stimulating hormone, dehydroepiandrosterone, cortisol, aldosterone, adrenomedullin, interstitial testosterone, insulin, parathyroid hormone, thyroid hormone, antidiuretic hormone, and adrenocorticotropic hormone
Oxygen free radical parameters	Peroxynitrous acid, small molecule free radical, hydrogen peroxide free radical, superoxide anion radical, hydroxyl radical
Neurotransmitter parameters	acetylcholine, catecholamine, dopamine, serotonin

(B)

Fig. 3. (A) Automatic biochemical analyzer
Fig. 3 (B) Parameters of electro interstitial scan system.

metabolomics, pharmacogenomics, genomics, physiological and biochemical analysis, and immunology diagnosis. AI assists in the analysis of images generated by these diagnostic tools.

5.2. *Streamlined blood testing*

For patients requiring regular blood tests, especially for glucose, triglyceride, and total cholesterol levels, the intelligent system simplifies the process. Merely a single drop (12 μL) of fingertip blood is needed for these tests, producing accurate and automatic results within 15 min (Fig. 3 A). This approach significantly reduces patient discomfort and enhances compliance.

5.3. *Electrical interstitial scan (EIS)*

The system also incorporates EIS, a non-invasive examination method utilizing bio-impedance, electrochemistry, and physiology theories to measure electrical conductance. EIS provides reproducible measurements that serve as disease markers or indicators of treatment response [16]. EIS data are transmitted to big data for AI analysis (Fig. 3 B).

5.4. *Baseline information*

A total of 106 patients (51 in the intelligent group and 55 in the control group), who met the inclusion criteria, were ultimately included in the analysis. Nine patients were excluded due to incomplete information. The reliability and validity of the satisfaction questionnaire were 83.70 % and 85.76 %, respectively.

5.5. *Comparison of basic information between intelligent group and control group*

There was no statistical difference in age ($p = 0.839$), gender ($p = 0.881$), education ($p = 0.297$) or income ($p = 0.123$) level between intelligent group and control group (Table 1).

5.6. *Comparison of satisfaction score between intelligent group and control group*

We observed significant differences in five satisfaction aspects: 1) the physical examination environment; 2) the attitude and responsiveness of doctors; 3) the attitude and responsiveness of nurses; 4) the effectiveness of obtaining results; and 5) the information provided regarding physical examination and medical advice ($p < 0.001$). The total score also showed a statistically significant difference ($p < 0.001$) (see Table 2).

Furthermore, after adjusting for education and income levels, both with p values below 0.3 in the previous analysis, the observed differences remained statistically significant ($p < 0.001$). The total score's p-value was 0.004 in the multivariable logistic regression model (see Table 3).

6. Discussion

In this paper, we systematically introduced the completed design, application, and evaluation process of an intelligent physical examination system. Based on the results and findings from a series of studies conducted during the system's development, this article

Table 1
Comparison of basic information between intelligent group and control group.

Parameters	All subjects (n = 106)	Intelligent group (n = 51)	Traditional group (n = 55)	P value
Age (year)				0.839
≤30	13(12.3 %)	8 (15.69 %)	5 (9.09 %)	
31–40	21(19.8 %)	10 (19.61 %)	11 (20.00 %)	
41–50	31(29.2 %)	15 (29.41 %)	16 (29.10 %)	
51–60	31(29.2 %)	13 (25.49 %)	18 (32.73 %)	
≥60	10(9.4 %)	5 (9.80 %)	5 (9.09 %)	
Sex				0.881
Male	34(32.1)	16 (31.37 %)	18 (32.73 %)	
Female	72(67.9)	35 (68.63 %)	37 (67.27 %)	
Education (year)				0.297
≤12(Senior high school)	26(24.5 %)	12 (23.53 %)	14 (25.45 %)	
13-16(Junior college/undergraduate)	65(61.3 %)	29 (56.86 %)	36 (65.45 %)	
≥17 (Postgraduate)	15(14.2 %)	10 (19.61 %)	5 (9.09 %)	
Income (yuan/month)				0.123
＜5000	2(1.9 %)	0 (0.00 %)	2 (3.64 %)	
5000–10000	23(21.7 %)	10 (19.61 %)	13 (23.64 %)	
10,000–20000	57(53.8 %)	25 (49.02 %)	32 (58.18 %)	
＞20,000	24(22.6 %)	16 (31.37 %)	8 (14.55 %)	

The categorical variables expressed as number(percentage).

Table 2
Comparison of satisfaction score between intelligent group and control group.

Satisfaction measures	All subjects (n = 106)	Intelligent group (n = 51)	Traditional group (n = 55)	P value
Environment	4.46 ± 0.758	4.94 ± 0.238	4.02 ± 0.805	< 0.001
Attitude and responsiveness of doctors	4.49 ± 0.746	4.96 ± 0.196	4.05 ± 0.803	< 0.001
Attitude and responsiveness of nurses	4.48 ± 0.746	4.96 ± 0.196	4.04 ± 0.973	< 0.001
Efficiency of obtaining physical examination results	4.48 ± 0.771	4.94 ± 0.238	4.05 ± 0.848	< 0.001
Information of physical examination results and medical advices	4.55 ± 0.500	4.90 ± 0.300	4.22 ± 0.417	< 0.001
Total score	22.46 ± 2.768	24.71 ± 0.502	20.38 ± 2.345	< 0.001

The continuous variable expressed as mean ± standard deviation.

provides reliable methodological experiences and a basis for researchers to develop more feasible and effective physical examination systems.

We found higher satisfaction scores among patients undergoing physical examinations in the intelligent system. Improving patient satisfaction is crucial for the doctor-patient relationship, doctor enthusiasm, patient compliance, and chronic disease management. A study encompassing all participating hospitals in the Hospital Consumer Assessment of Healthcare Providers and Systems patient survey indicated an association between higher patient satisfaction and better stroke outcomes [17]. Similarly, a study conducted in outpatient clinics emphasized the significance of patient satisfaction in consultation quality, linking it to improved clinical competence and skills among physicians [18]. These results underscore the importance of patient satisfaction in disease management. Future research directions could focus on enhancing patient satisfaction while reducing costs, potentially achieved through technological advancements. Studies exploring e-Health applications and mobile-health interventions demonstrated significant improvements in patient experience and satisfaction [19–21]. Additionally, recent research involving an AI-assisted program showcased reduced patient waiting times and enhanced visit satisfaction by streamlining outpatient service procedures [22]. Our study and these findings collectively confirm the effectiveness of the IoHT in enhancing patient satisfaction.

The advancement of AI and IoT enables complete automation of data collection, facilitating swift and accurate analysis within health big data. Previous studies have highlighted the widespread utilization of AI in healthcare, nursing, and physical examinations, particularly for patients with chronic diseases [23–25]. Guided by pertinent clinical inquiries, powerful AI techniques can unearth clinically relevant information from vast datasets, aiding clinical decision-making [26,27]. While AI cannot entirely replace human physicians, it can significantly assist them in making better clinical decisions or even supplant human judgment in specific healthcare functional domains. This could be a crucial factor contributing to higher patient satisfaction scores in intelligent physical examinations. Furthermore, this could enhance efficiency and alleviate crowding in physical examination environments. Moreover, the integration of TCM into the intelligent system, with exclusively non-invasive TCM examinations, could also be a key reason for the higher satisfaction scores among patients receiving intelligent physical examinations.

Patients in the intelligent group exhibited higher satisfaction with doctors' attitudes. This may be attributed to AI technology substantially reducing doctors' information recording and analysis burden, allowing them more time for effective patient communication [28,29]. Additionally, the health big data associated with this intelligent system can deliver detailed and personalized medical advice based on individual examination results. These advices encompass various aspects such as diet, emotional regulation, acupressure, medicated baths, and further physical examinations. Moreover, the system translates TCM information into standardized data for evaluating patients' health conditions. This provision of qualified information aids disease development analysis and enables doctors to formulate comprehensive medical advice [30–32]. The integration of TCM and Western medicine theories not only fosters TCM development but also enhances patient satisfaction within this intelligent system.

Table 3
Association between satisfaction score and different groups.

	Unadjusted		Multivariable adjusted	
Satisfaction measures	OR (95 % CI)	P value	OR (95 % CI)	P value
Environment	32.889(9.006,120.111)	< 0.001	33.677 (8.587,132.082)	< 0.001
Attitude and responsiveness of doctors	46.421(10.161,212.081)	< 0.001	93.733(11.213,283.557)	< 0.001
Attitude and responsiveness of nurses	50.361(10.993,230.714)	< 0.001	56.104(10.823,290.822)	< 0.001
Efficiency of obtaining physical examination results	25.903(7.152,93.827)	< 0.001	38.522(8.985,165.167)	< 0.001
Information of physical examination results and medical advices	32.967(10.724,101.347)	< 0.001	34.430(10.442,113.525)	< 0.001

OR：odds ratio; CI: confidence interval.

6.1. Study limitations

It's important to acknowledge the limitations of this study. Firstly, additional data is required to support other functions of this system, such as its efficacy in chronic disease management and its impact on improving the satisfaction of doctors and nurses. Secondly, since the questionnaire study was entirely voluntary, there might be concerns regarding authenticity, particularly regarding income data, a potentially sensitive issue in China. Thirdly, while we initially explored the system's effectiveness in enhancing patient satisfaction, the sample size was small, and the questionnaire lacked more detailed items (e.g., disease distribution, disease course, etc.). Hence, future studies will aim to gather more comprehensive information to address these concerns and quantitatively and scientifically measure the system's effectiveness.

7. Conclusions

The results demonstrate that the intelligent physical examination system capitalized on AI and the integration of TCM and Western medicine, leading to a significant optimization of the medical examination process. Compared to the traditional physical examination system, the intelligent system notably enhanced patient satisfaction. Future optimization of the system could involve the incorporation of chronic disease follow-up technology.

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Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Xin Chen: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Ruxin Duan:** Investigation, Data curation. **Yao Shen:** Software, Data curation. **Hua Jiang:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Xin Chen reports financial support was provided by Youth Development Program for Youth Medical Talents of Shanghai East Hospital. Hua Jiang reports financial support was provided by Municipal Health Commission of Pudong New Area. Hua Jiang reports financial support was provided by Shanghai Municipal Health Commission. Hua Jiang reports financial support was provided by National Key Research and Development Program of China. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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