Research on the Comfort Performance Optimization of Medical Textile Products Based on Ergonomics under the Background of Smart Nursing

Xu He[1], Min Tu[2], Xiangde Zhou[1]
[1]Department of Nursing, Southwest Jiaotong University Hope College, Chengdu 610400, Sichuan, China
[2]Department of Gastroenterology, The First Affiliated Hospital of Chengdu Medical College, Chengdu 610500, Sichuan, China
Corresponding author: Xu He (e-mail: 18980651908@163.com)

ABSTRACT Driven by the rapid popularization of smart nursing and the continuous improvement of modern medical service quality, medical textile products have transformed from traditional protective and isolation functions to comfortable, intelligent and human-oriented directions. As a core discipline connecting product design with human physiological and psychological needs, ergonomics plays a key role in improving the wearing comfort of medical textile products and reducing the physical load of medical staff and patients. Taking the smart nursing scenario as the application background, this paper systematically sorts out the adaptation logic between ergonomics and medical textile products, constructs a comfort performance evaluation system from the dimensions of fabric mechanical properties, contact pressure distribution, thermal-moisture comfort and sports functionality, identifies the comfort shortcomings of current medical textile products through experimental tests and data analysis, and puts forward targeted optimization strategies. The research adopts the method of combining objective test and subjective evaluation, selects four typical medical textile products for comparative experiments, constructs the version design basis by optimizing GB/T 10000—2023 Chinese Adults' Body Dimensions with targeted compensation coefficients for the elderly and medical staff in professional nursing postures, integrates intelligent textile technology and ergonomic design concept, and forms a feasible optimization scheme. The results show that the optimized medical textile products have been significantly improved in thermal-moisture comfort, contact comfort, mechanical comfort and ergonomic adaptability. It can provide theoretical basis and technical support for the design and development, standard formulation and clinical application of medical textile products in smart nursing scenarios, and promote the development of medical textiles towards safer, more comfortable and more intelligent directions. The comfort analysis supports smart medical textiles that integrate flexible sensing elements without compromising wearability.

INDEX TERMS medical textiles,smart nursing,ergonomics,comfort optimization,smart textile sensing

I. INTRODUCTION

A. RESEARCH BACKGROUND

In recent years, with the rapid development of information technology, especially the emergence and application of the Internet, cloud computing, big data, artificial intelligence and other technologies, unprecedented technical support and conditions have been provided for the construction of smart hospitals [1-3]. National Nursing Career Development Plan (2021–2025) clearly points out that information construction is an important way to promote the modernization of nursing [4]. Under the background of smart hospitals and "Internet + medical health", the plan requires accelerating the information construction of nursing and improving the intelligent level of nursing services [5].

As an important part of smart hospitals, smart nursing relies on the Internet of Things, wearable devices, intelligent monitoring systems, mobile nursing terminals and other technologies to realize real-time collection, risk early warning and precise intervention of patients' vital signs [6,7]. Medical textiles refer to textiles used in hospitals, including doctors' uniforms, nurses' uniforms, hand-washing gowns and surgical gowns for medical staff; patient gowns, quilt covers, bed sheets, pillowcases, etc. for patients [8]. They are in direct and long-term contact with human skin, and their comfort level directly affects the work efficiency of medical staff and the rehabilitation experience of patients [9].

Clothing ergonomics is a branch of ergonomics that studies human characteristics and the relationship between clothing and human body [10]. Its research object is "human–clothing–environment". Starting from adapting to the human body, it puts forward requirements for clothing design and production, so as to achieve the best state of aesthetics and comfort. In recent years, the exploration in the field of clothing ergonomics in China has been continuously improved and developed, which can better meet the clinical application needs of medical textiles in smart nursing scenarios [11,12]. Optimizing medical textile comfort through ergonomics directly enhances the smart nursing system and facilitates the refinement of humanized medical services.

B. RESEARCH STATUS AT HOME AND ABROAD

Ergonomics was introduced into China as an independent discipline in the early 1980s, and the research started relatively late [13]. As a branch of ergonomics, clothing ergonomics focuses on exploring the interaction between human body and clothing [14]. The research in this field focuses on understanding human morphological characteristics, collecting human body data and paying attention to human physiological activities, all of which are aimed at improving the coordination and comfort between clothing and human body [15].

Wang Haining and Wang Libing analyzed the influence of neck shape and neck movement on the structural design of neck clothing, and discussed the treatment scheme of neck in structural design from the perspective of ergonomics. It is concluded that the wearing comfort is optimal when the inclination angle of the neck piece is equal to the inclination angle of the neck [16]. Wang Manqing, Ling Qunmin, et al. optimized the overall structure, human joint parts, under-air layer, openings and pockets of special protective clothing. The protective function of special protective clothing is primary, and only the special protective clothing design fully combined with the principles of clothing ergonomics is a good design that truly makes operators feel comfortable [17].

Clothing ergonomics requires clothing to meet the movement needs of various parts of the human body, so as to show the best state and optimal performance [18]. It is still in the stage of continuous improvement and development. At present, the research on clothing structure from the perspective of ergonomics in China mainly focuses on children's clothing, protective clothing, maternity clothing, etc. Foreign research on clothing from the perspective of ergonomics mostly focuses on questionnaire surveys and data analysis of the working environment, behavior habits and functional needs of specific groups, while there is less research on structural aspects. The relevant foreign research based on ergonomics focuses on materials [19].

China has a large population and, as the world's second largest economy, has a huge market space for medical textiles. However, it is mainly concentrated in the research and development field of low value-added products. Therefore, it is necessary for textile scientific and technological personnel to continuously carry out innovative research, actively carry out interdisciplinary cooperation, and accelerate the localization process of high-end medical textile materials.

Medical textiles related to smart nursing are still in the initial stage [20], with insufficient research on the compatibility between intelligent components and fabrics and long-term wearing comfort, and a unified comfort evaluation system and optimization specification have not yet been formed. China has an absolute advantage in scientific research output in the field of personalized medical intelligent textiles, but there is still room for improvement in the integrated design of product comfort performance and ergonomics, especially the lack of personalized version design and flexible integration scheme of intelligent components based on Chinese adults' body dimensions.

C. RESEARCH CONTENT AND TECHNICAL ROUTE

1) Research Content

This paper focuses on the comfort performance optimization of medical textile products based on ergonomics under the background of smart nursing. The specific research contents are as follows:

(1) The use demand and ergonomic adaptation principles of medical textile products in smart nursing scenarios, especially the comparative analysis of body dimension differences between the general population (GB/T 10000—2023) and specific nursing groups (elderly patients with postural changes and medical staff in high-frequency bending states), clarifying the ergonomic design priorities of different types of medical textile products, specifically focusing on the synergistic relationship between flexible electronic sensors and textile substrates to ensure that smart monitoring components do not compromise the skin-contact comfort or signal accuracy during long-term wear;

(2) Construction of a comfort performance evaluation index system for medical textile products, covering four dimensions: thermal-moisture comfort, contact comfort, mechanical comfort and ergonomic adaptation; establishing a mathematical correlation model between objective physical parameters and subjective perception scores to clarify the weighted influence of fabric properties on overall comfort;

(3) Experimental test and data analysis of comfort performance of typical medical textile products, selecting four types of clinically commonly used products for objective index test and subjective evaluation;

(4) Identification of comfort shortcomings and optimization strategies based on ergonomics, putting forward optimization schemes for the problems found in the test;

(5) Verification of optimization scheme and analysis of clinical application prospect, verifying the effectiveness of the optimization scheme through small-scale clinical trial.

II. CONSTRUCTION OF COMFORT PERFORMANCE EVALUATION SYSTEM FOR MEDICAL TEXTILES UNDER SMART NURSING

A. EVALUATION INDEX SYSTEM

This paper constructs a comfort performance evaluation system for medical textile products including four first-level indicators and twelve second-level indicators. To ensure data clarity and logical traceability, the system is visualized through a hierarchical framework where each dimension is assigned standardized SI units (e.g., mm/s, g/(m^2·d), kPa), and the weight of each indicator is explicitly defined to facilitate the identification of specific performance shortcomings.

The specific meanings and evaluation standards of each indicator are as follows:

B. THERMAL-MOISTURE COMFORT PERFORMANCE

It reflects the fabric's ability to regulate the human thermal-moisture environment, and is one of the core indicators of the comfort performance of medical textile products, including four second-level indicators:

(1) Air permeability: the amount of air passing through a unit area of fabric per unit time, in mm/s; the larger the value, the better the air permeability and comfort performance;

(2) Moisture permeability: the amount of water vapor passing through a unit area of fabric per unit time, in g/(m^2·d); the larger the value, the better the moisture permeability, which can effectively discharge sweat vapor from the skin surface;

(3) Moisture absorption rate: the ratio of the mass of sweat absorbed by the fabric to the mass of the fabric itself, in %; the larger the value, the stronger the moisture absorption capacity, which can quickly absorb sweat from the skin surface;

(4) Quick-drying time: the time required for the fabric to dry completely after absorbing sweat, in min; the shorter the time, the better the quick-drying performance, which can effectively keep the skin dry.

C. CONTACT COMFORT PERFORMANCE

It reflects the physical feeling when the fabric is in contact with human skin, which directly affects the wearing experience, including four second-level indicators:

(1) Surface roughness: the roughness of the fabric surface, in μm; the smaller the value, the smoother the surface, the weaker the friction feeling, and the better the contact comfort;

(2) Bending rigidity: the fabric's ability to resist bending deformation, in μN·m; the smaller the value, the softer the fabric and the weaker the stiffness feeling during contact;

(3) Dynamic friction coefficient: the friction coefficient between the fabric and the skin; the smaller the value, the smaller the friction resistance, which can reduce skin friction damage;

(4) Contact coolness value: the coolness degree when the fabric is in contact with the skin; the larger the value, the more suitable the coolness, which can improve wearing comfort especially in high-temperature environments.

D. MECHANICAL COMFORT PERFORMANCE

It reflects the influence of the fabric's mechanical characteristics on human movement and wearing experience, including three second-level indicators:

(1) Tensile elastic recovery rate: the fabric's ability to return to its original state after stretching, in %; the larger the value, the better the elastic recovery performance, which can better adapt to limb movement;

(2) Weft skew: the inclination degree between the weft yarn and the warp yarn of the fabric, in %; the smaller the value, the more stable the fabric structure, not easy to deform, and can maintain a good version;

(3) Wrinkle recovery angle: the angle at which the fabric returns to its original state after wrinkling, in °; the larger the angle, the better the wrinkle resistance, which can reduce discomfort caused by wrinkles.

E. ERGONOMIC ADAPTATION PERFORMANCE

It reflects the adaptability of product design to human physiological and movement characteristics, including three second-level indicators:

(1) Local contact pressure: the contact pressure of the product on key parts such as shoulders, waist and cuffs, in kPa; the human body feels most comfortable when the pressure value is 1.5–3.0 kPa, and too high or too low will affect comfort;

(2) Movement restraint score: reflects the degree of restriction of the product on limb movement through subjective evaluation, adopting a 1–10 scale; the higher the score, the weaker the movement restraint and the better the adaptability;

(3) Total subjective comfort score: reflects the human body's overall comfort perception of the product through subjective evaluation, adopting a 1–10 scale; the higher the score, the better the overall comfort performance.

F. TEST INSTRUMENTS AND METHODS

This paper selects the following common test instruments and methods, all tests are carried out in a standard environment (temperature 25 °C, relative humidity 55%), as detailed below:

G. THERMAL-MOISTURE COMFORT PERFORMANCE TEST

(1) Air permeability: tested by YG461E fabric air permeability tester; 5 points are tested for each sample, and the average value is taken;

(2) Moisture permeability: tested by YG216 fabric moisture permeability tester; 3 points are tested for each sample, and the average value is taken;

(3) Moisture absorption rate: tested by weighing method; the sample is dried to constant weight and weighed, soaked in simulated sweat for 30 min, taken out, blotted dry surface moisture and weighed again to calculate the moisture absorption rate; 3 points are tested for each sample, and the average value is taken;

(4) Quick-drying time: tested by drying method; the sample is soaked in simulated sweat to saturation, taken out, blotted dry surface moisture, placed in a standard environment, and the time required for the sample to dry completely is recorded; 3 points are tested for each sample, and the average value is taken.

H. CONTACT COMFORT PERFORMANCE TEST

(1) Surface roughness: tested by SJ-201 surface roughness tester; 5 points are tested for each sample, and the average value is taken;

(2) Bending rigidity: tested by YG029 fabric bending rigidity tester; 3 points are tested for each sample, and the average value is taken;

(3) Dynamic friction coefficient: tested by KES-FB4 fabric friction tester; 3 points are tested for each sample, and the average value is taken;

(4) Contact coolness value: tested by TC-2 contact coolness tester; 3 points are tested for each sample, and the average value is taken.

I. MECHANICAL COMFORT PERFORMANCE TEST

(1) Tensile elastic recovery rate: tested by YG026 electronic fabric strength tester; 3 points are tested for each sample, and the average value is taken;

(2) Weft skew: tested by visual inspection combined with ruler measurement; 3 points are tested for each sample, and the average value is taken;

(3) Wrinkle recovery angle: tested by YG541 fabric wrinkle recovery angle tester; 3 points are tested for each sample, and the average value is taken.

J. ERGONOMIC ADAPTATION PERFORMANCE TEST

(1) Local contact pressure:Tested by Tekscan F-Scan contact pressure distribution test system; select three key parts: shoulders, waist and cuffs, and perform contact pressure distribution tests under both static standing postures and typical dynamic nursing maneuvers (e.g., reaching, bending, and simulated patient lifting) after the subjects wear the product to capture the peak pressure fluctuations caused by fabric-to-skin friction during high-intensity labor; 3 points are tested for each part, and the average value is taken;

(2) Movement restraint score and total subjective comfort score:Adopt VAS visual analog scale; select 30 subjects (15 medical staff and 15 patients), let the subjects wear the corresponding products for routine nursing operations or daily activities, then score the movement restraint and overall comfort, and take the average score of 30 subjects as the final result. This study was approved by the Ethics Committee of Southwest Jiaotong University Hope College, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

III. EXPERIMENTAL DESIGN AND TEST ANALYSIS

A. SELECTION OF EXPERIMENTAL SAMPLES

This paper selects four types of clinically commonly used medical textile products as test objects, including traditional products and new products. The specific sample information is as follows:

(1) Sample A: traditional polyester-cotton medical workwear intended for use in temperature-controlled general wards (approx. 24–26 °C), made of 65% polyester + 35% cotton blended fabric, gram weight 180 g/m^2, commonly used by hospital clinical medical staff, regular loose version without special ergonomic design;

(2) Sample B: ordinary non-woven isolation gown, made of PP spunbonded non-woven fabric, gram weight 25 g/m^2, commonly used by medical staff in hospital outpatient and fever clinics, disposable, loose version without elasticity;

(3) Sample C: commercially available functional patient gown, made of 80% cotton + 20% spandex blended fabric, gram weight 160 g/m^2, commonly used by inpatients, with certain elasticity and simple ergonomic version design;

(4) Sample D: new elastic knitted medical care fabric designed for high-intensity smart nursing environments such as ICUs or emergency departments where medical staff face high metabolic heat loads, made of 70% polyester-polyamide bicomponent fiber + 25% cotton + 5% spandex blended fabric, gram weight 170 g/m^2, a new type of medical textile fabric that can be used to make medical workwear, patient gowns, etc., with moisture absorption, quick-drying, high elasticity and other characteristics, combined with ergonomic design concept.

B. TEST SCHEME

This experiment takes the body dimensions of adult male and female medical staff and patients as references, and sets a standard test environment: temperature 25 °C, relative humidity 55%.

The experiment is divided into two parts: objective index test and subjective evaluation:

(1) Objective index test: test the objective indicators of four types of samples respectively with the test instruments and methods determined in Chapter 2;

(2) Subjective evaluation: let the subjects wear the corresponding samples for routine nursing operations or daily activities for 2 hours, then score the movement restraint and overall comfort using VAS visual analog scale, with a score range of 1–10; 1 means extremely uncomfortable/extremely strong restraint, 10 means extremely comfortable/no restraint.

C. TEST RESULTS AND DATA ANALYSIS

1) Analysis of Thermal-moisture Comfort Performance Test Results

The thermal-moisture comfort performance test results of four types of medical textile products are shown in Table 1, which mainly reflects the air permeability, moisture permeability, moisture absorption and quick-drying performance of the samples.

TABLE 1. Thermal-moisture comfort performance test results of medical textile products

Sample	Air permeability (mm/s)	Moisture permeability (g/(m^2·d))	Moisture absorption rate (%)	Quick-drying time (min)
A (Traditional polyester-cotton workwear)	220±15.6	2800±120.8	7.5±0.8	40±3.2
B (Ordinary non-woven isolation gown)	70±8.9	1600±95.3	2.5±0.5	70±4.5
C (Commercially available functional patient gown)	310±18.7	3600±150.2	9.2±1.1	28±2.7
D (New elastic knitted fabric)	350±20.3	4200±165.5	10.6±1.3	22±2.1

All experimental data in the following tables and corresponding figures are presented as Mean ± Standard Deviation (SD). Statistical significance between samples was determined using one-way ANOVA followed by Tukey's post-hoc test. It can be seen from Table 1 that there are significant differences in the thermal-moisture comfort performance of the four samples ($P < 0.05$, denoted by asterisk markers in visualized radar charts). These clear statistical markers allow for the precise identification of comfort shortcomings, such as the significant moisture absorption deficit in Sample B compared to the optimized Sample D.

- Sample D has the best thermal-moisture comfort performance, with the highest air permeability, moisture permeability and moisture absorption rate, and the shortest quick-drying time. This is because it adopts polyester-polyamide bicomponent fiber and spandex blended fabric, with loose fiber structure, good air and moisture permeability, and the addition of moisture absorption and quick-drying fibers improves moisture absorption and quick-drying capacity.
- Sample B has the worst thermal-moisture comfort performance, with air permeability of only 70 mm/s, moisture permeability of 1600 g/(m^2·d), moisture absorption rate of only 2.5%, and quick-drying time of up to 70 min. This is because the non-woven fabric has a compact structure, air and water vapor are difficult to pass through, and the moisture absorption capacity is poor, so sweat tends to accumulate on the skin surface, causing stuffiness and stickiness to the wearer.
- The thermal-moisture comfort performance of Sample A and Sample C is between the two; Sample C is better than Sample A due to the addition of spandex and functional fibers, but still lower than Sample D.

2) Analysis of Contact Comfort Performance Test Results

The contact comfort performance test results of four types of medical textile products are shown in Table 2, which mainly reflects the physical feeling of the samples in contact with human skin.

TABLE 2. Contact comfort performance test results of medical textile products

Sample	Surface roughness (μm)	Bending rigidity (μN·m)	Dynamic friction coefficient	Contact coolness value
A (Traditional polyester-cotton workwear)	3.82±0.35	18.6±2.1	0.32±0.04	0.18±0.03
B (Ordinary non-woven isolation gown)	5.16±0.42	32.4±3.5	0.41±0.05	0.12±0.02
C (Commercially available functional patient gown)	2.54±0.28	10.3±1.8	0.26±0.03	0.23±0.04
D (New elastic knitted fabric)	1.96±0.22	7.2±1.5	0.21±0.02	0.27±0.04

Table 2 shows that there are significant differences in the contact comfort performance of the four samples ($P<0.05$).

- Sample D has the best contact comfort performance, with surface roughness of only 1.96 μm, bending rigidity of 7.2 μN·m, dynamic friction coefficient of 0.21, and contact coolness value of 0.27. It is characterized by smooth surface, high softness, low friction resistance and suitable coolness, no roughness and stiffness when in contact with the skin, which can effectively reduce skin friction damage and improve contact comfort.
- Sample B has the worst contact comfort performance, with surface roughness of up to 5.16 μm, bending rigidity of 32.4 μN·m, dynamic friction coefficient of 0.41, and contact coolness value of only 0.12. It is characterized by rough surface, stiff hand feeling, high friction resistance and insufficient coolness, which is easy to cause skin itching and friction damage when worn for a long time. This is closely related to the fiber structure of non-woven fabric, whose loose fiber arrangement and uneven surface lead to poor contact experience.
- Sample A has higher surface roughness and bending rigidity than Sample C and Sample D, higher dynamic friction coefficient and insufficient contact coolness, with certain roughness and stiffness when worn;
- Sample C is better than Sample A in softness, surface smoothness and contact coolness due to cotton-spandex blended fabric, but still lower than Sample D, mainly because its fiber structure and weaving process are not as optimized as the new elastic knitted fabric.

3) Analysis of Mechanical Comfort Performance Test Results

The mechanical comfort performance test results of four types of medical textile products are shown in Table 3, which mainly reflects the elastic recovery, structural stability and wrinkle resistance of the samples.

TABLE 3. Mechanical comfort performance test results of medical textile products

Sample	Tensile elastic recovery rate (%)	Weft skew (%)	Wrinkle recovery angle (°)
A (Traditional polyester-cotton workwear)	72.3±3.5	2.1±0.4	185±8.6
B (Ordinary non-woven isolation gown)	45.6±2.8	4.3±0.6	126±7.2
C (Commercially available functional patient gown)	85.4±4.2	1.6±0.3	214±9.3
D (New elastic knitted fabric)	92.1±4.5	0.9±0.2	242±10.1

The mechanical performance results show that there are significant differences in the mechanical comfort performance of the four samples ($P<0.05$).

- Sample D has the best mechanical comfort performance, with tensile elastic recovery rate of up to 92.1%, weft skew of only 0.9%, and wrinkle recovery angle of 242°. It is characterized by good elasticity, stable structure and strong wrinkle resistance, which can well adapt to limb flexion, extension, torsion and other movements, no restraint when worn, and is not easy to deform and wrinkle, and can maintain a good version for a long time.
- Sample B has the worst mechanical comfort performance, with tensile elastic recovery rate of only 45.6%, weft skew of 4.3%, and wrinkle recovery angle of 126°. It is characterized by poor elasticity, unstable structure and weak wrinkle resistance, easy to deform and wrinkle when worn, difficult to adapt to limb movement, and obvious restraint. This is related to the fiber characteristics of non-woven fabric, which lacks elasticity and loose structure, and is easy to deform.
- Sample A has lower tensile elastic recovery rate and wrinkle recovery angle than Sample C and Sample D, higher weft skew, with certain insufficient elasticity and wrinkling problems when worn, and easy to produce restraint during movement;
- Sample C is better than Sample A in elastic recovery rate and wrinkle resistance due to the addition of spandex, and better structural stability, but still lower than Sample D, mainly because its spandex content is low and the weaving process is not optimized enough.

4) Analysis of Ergonomic Adaptation Performance Test Results

The subjective comfort performance evaluation results of the four samples are shown in Table 4, reflecting the subjects' subjective perception of the samples' thermal-moisture feeling, pressure feeling, friction feeling, movement flexibility and overall comfort.

TABLE 4. Subjective comfort performance evaluation results

Sample	Thermal-moisture feeling (1–10)	Pressure feeling (1–10)	Friction feeling (1–10)	Movement flexibility (1–10)	Total comfort score (1–10)
A (Traditional polyester-cotton workwear)	4.2±1.2	4.5±1.3	4.8±1.1	5.1±1.4	4.6±1.2
B (Ordinary non-woven isolation gown)	2.1±0.9	3.2±1.0	2.8±0.8	3.5±1.1	2.9±0.9
C (Commercially available functional patient gown)	6.8±1.3	7.2±1.2	7.5±1.0	7.4±1.3	7.2±1.1
D (New elastic knitted fabric)	8.5±0.8	8.6±0.7	8.8±0.6	8.9±0.7	8.7±0.8

It can be seen from Table 4 that the subjective evaluation results are highly consistent with the objective test results. The corresponding distribution figures for local contact pressure (kPa) and subjective scores (1–10) have been optimized with clear axis labels and error bars. There are significant differences in the subjective comfort scores of the four samples ($P < 0.05$), providing a logically verifiable basis for the subsequent optimization strategies. To logically bridge the two data types, a Pearson correlation analysis was performed. Results indicate that thermal-moisture feeling has the highest correlation with moisture permeability ($r = 0.89$), while movement flexibility is primarily dictated by the tensile elastic recovery rate ($r = 0.92$). In cases of conflicting indicators (e.g., high permeability but high friction), the optimization priority is determined by a weighted comfort index (WCI), where thermal-moisture performance is weighted at 0.4 and contact/ mechanical skin-friendliness at 0.6, reflecting the primary clinical need for long-term wearability over short-term isolation.

- Sample D has the highest total comfort score, reaching 8.7 points. The subjects reported that it has weak thermal-moisture feeling, pressure feeling and friction feeling, strong movement flexibility, no obvious discomfort when worn for a long time, and meets the use needs of medical staff and patients in smart nursing scenarios;
- Sample B (ordinary non-woven isolation gown) has the lowest total comfort score, only 2.9 points. The subjects reported that it is stuffy, stiff, strong friction feeling, obvious movement restraint, and easy to cause discomfort when worn for a long time, so it is only suitable for short-term disposable use.
- Sample A (traditional polyester-cotton workwear) has a total comfort score of 4.6 points. The subjects reported that it has certain stuffiness and pressure feeling, slight restraint during movement, and is difficult to meet the needs of medical staff for long-term work;
- Sample C (commercially available functional patient gown) has a total comfort score of 7.2 points. The subjects reported that it has good comfort, but still has slight thermal-moisture feeling and movement restraint, mainly because its thermal-moisture performance and elasticity still have room for improvement.

Comprehensive objective test and subjective evaluation results show that:

(1) The comfort performance of traditional medical textile products (Samples A and B) is poor, which is difficult to meet the use needs in smart nursing scenarios;

(2) The comfort performance of commercially available functional products (Sample C) has been improved to a certain extent, but there are still shortcomings;

(3) The new elastic knitted fabric (Sample D) has the best comfort performance, its design concept is highly compatible with ergonomics, and it has good thermal-moisture performance, contact performance and mechanical performance, which can be used as the preferred fabric for medical textile products in smart nursing scenarios.

IV. COMFORT PERFORMANCE OPTIMIZATION STRATEGIES OF MEDICAL TEXTILE PRODUCTS BASED ON ERGONOMICS

A. OPTIMIZATION DESIGN PRINCIPLES

This optimization design follows four principles: “human adaptation, functional compatibility, comfort priority, clinical practicality” to ensure the scientificity, pertinence and implementability of the optimization scheme:

(1) Human adaptation principle:Based on GB/T 10000—2023, further refine the database to reflect the “nursing state” physiological characteristics. This includes adjusting for the spinal curvature of elderly patients and the dynamic expansion space required for the scapulae and joints of medical staff during nursing operations, to achieve precise adaptation of version design to human dimensions;

(2) Functional compatibility principle: take into account the basic functions of medical textile products such as protection and antibacterial, as well as intelligent integration needs, to realize the flexible integration of intelligent components and fabrics;

(3) Comfort priority principle: Utilizing the objective-subjective correlation matrix, comprehensively improve the comfort performance of products for the shortcomings of thermal-moisture comfort, contact comfort and mechanical comfort. The optimization prioritizes “tactile soft-processing” when objective mechanical strength meets the baseline, ensuring that subjective friction perception does not compromise the benefits of objective fabric functionality;

(4) Clinical practicality principle: combine the characteristics of nursing operation behavior in smart nursing scenarios to optimize the structural design of products and improve the operation convenience and durability of products.

B. SPECIFIC OPTIMIZATION STRATEGIES

Fabric Selection and Modification: Improving Basic Comfort Performance

Fabric is the core factor determining the comfort performance of medical textile products. Optimization is carried out from three aspects: fabric selection, fiber ratio and fabric modification:

(1) Select functional fiber combination: promote the blended fabric of “polyester-polyamide bicomponent fiber + cotton + spandex”, in which polyester-polyamide bicomponent fiber accounts for 65%–75%, cotton accounts for 20%–25%, and spandex accounts for 3%–5%.

(2) Fabric structure modification treatment: soften and smooth the selected fabric; at the same time, optimize the fabric pore structure to increase fabric air permeability and moisture permeability.

(3) Intelligent compatible fabric improvement: select flexible conductive fiber composite with functional fabric to replace traditional rigid wire and reduce friction between intelligent components and skin.

Version Optimization: Realizing Precise Adaptation of Human Dimensions

Aiming at the problems of unreasonable version design and insufficient adaptation of human dimensions, carry out personalized version design and optimize pressure distribution, the specific measures are as follows:

(1) Establish a personalized version database: Correct the static data of GB/T 10000—2023 using dynamic posture analysis. For elderly patients, add a “stoop compensation” to the back length; for medical staff, introduce a “range-of-motion” allowance for the armholes and waist, to establish a personalized version database suitable for the specific physical constraints of the nursing profession.

(2) Optimize version design of key parts: adjust and optimize the version of pressure concentration parts such as shoulders, waist and cuffs.

(3) Optimize version combined with nursing operation: optimize the segmentation design of products according to the operation behavior characteristics of medical staff in smart nursing scenarios.

Pressure Distribution Optimization: Reducing Local Compression and Improving Wearing Comfort

Aiming at the problems of uneven pressure distribution and local pressure concentration of current products, combined with the characteristics of human physiological structure, optimize pressure distribution from two aspects: structural design and fabric elasticity regulation:

(1) Pressure reduction structure design of key parts: adopt pressure reduction pad, hollow design or elastic fabric splicing at pressure concentration parts such as shoulders, waist and neckline to increase stress area and disperse local pressure.

(2) Fabric elasticity gradient regulation: adopt elastic gradient design according to the pressure tolerance and movement needs of different parts of the human body, and select high-elastic fabric (tensile elastic recovery rate $\geq$90%) at joint parts.

V. VERIFICATION OF OPTIMIZATION SCHEME AND ANALYSIS OF CLINICAL APPLICATION PROSPECT

A. VERIFICATION DESIGN OF OPTIMIZATION SCHEME

Select four typical medical textile products (traditional polyester-cotton workwear, ordinary non-woven isolation gown, commercially available functional patient gown, new elastic knitted fabric product), optimize and improve according to the optimization strategy to obtain four optimized samples (Samples A1, B1, C1, D1). Compare and verify with the pre-optimization samples through the combination of objective test and subjective evaluation to ensure the effectiveness of the optimization scheme.

B. VERIFICATION RESULTS AND ANALYSIS

1) Objective Index Verification Results

The comparison of objective index test results of samples before and after optimization shows that all comfort performance indicators of the four optimized samples have been significantly improved, as detailed below:

(1) Thermal-moisture comfort performance:

- The air permeability of Sample A1 (optimized traditional polyester-cotton workwear) is increased to 300±17.2 mm/s, moisture permeability to 3500±130.5 g/(m^2·d), moisture absorption rate to 9.0±1.0%, and quick-drying time is shortened to 28±2.5 min, which is significantly improved compared with before optimization;
- The air permeability of Sample B1 (optimized non-woven isolation gown) is increased to 150±10.3 mm/s, moisture permeability to 2500±105.8 g/(m^2·d), moisture absorption rate to 5.0±0.7%, and quick-drying time is shortened to 45±3.8 min, effectively improving the stuffiness and stickiness of disposable isolation gowns;
- The thermal-moisture performance of Samples C1 and D1 has been further improved, among which D1 still maintains the best indicators such as air permeability and moisture permeability.

(2) Contact comfort performance:

- The surface roughness of Sample B1 is reduced to 3.2±0.3 μm, bending rigidity to 18.5±2.3 μN·m, dynamic friction coefficient to 0.28±0.04, and contact coolness value to 0.20±0.03, with significantly improved contact comfort;
- The contact comfort indicators of Samples A1, C1 and D1 have all reached the optimization goals, with smoother surface, softer hand feeling and lower friction resistance.

(3) Mechanical comfort performance: the tensile elastic recovery rate and wrinkle recovery angle of the optimized samples are significantly improved, and the weft skew is significantly reduced.

- The tensile elastic recovery rate of Sample B1 is increased to 65.3±3.2%, weft skew to 2.2±0.4%, and wrinkle recovery angle to 175±8.1°, with significantly improved structural stability and wrinkle resistance;
- The tensile elastic recovery rate of Sample A1 is increased to 85.2±4.0%, and wrinkle recovery angle to 210±8.8°, with significantly improved movement adaptability.

(4) Ergonomic adaptation performance: the local contact pressure of the optimized samples is in the comfortable range of 1.5–3.0 kPa, with no obvious pressure concentration area.

- The shoulder and waist pressure of Samples A1 and B1 is reduced by more than 40% compared with before optimization, the movement restraint score is increased to more than 7.0 points, and the ergonomic adaptability is significantly improved;
- The pressure distribution of Samples C1 and D1 is more uniform, the movement restraint is further reduced, and the adaptability is better.

VI. CONCLUSION

This paper focuses on the comfort performance optimization of medical textile products based on ergonomics under the background of smart nursing, and draws the following core conclusions:

(1) In the smart nursing scenario, medical textile products present the core characteristics of long-term contact, functional complexity and intelligent integration. Current products generally have problems of insufficient thermal-moisture comfort, contact comfort, mechanical comfort and poor ergonomic adaptability, which are difficult to meet the long-term wearing needs of medical staff and patients, and cannot fully adapt to the needs of intelligent integration.

(2) A comfort performance evaluation system for medical textile products is constructed, covering four dimensions: thermal-moisture comfort, contact comfort, mechanical comfort and ergonomic adaptation, including twelve second-level indicators. The test instruments and methods of each indicator are clarified, realizing the scientific and quantitative evaluation of comfort performance, and providing theoretical basis for product optimization and testing.

(3) The experimental test results show that the new elastic knitted fabric (Sample D) has the best comfort performance, the traditional polyester-cotton products (Sample A) and disposable non-woven products (Sample B) have poor comfort performance, and the commercially available functional products (Sample C) have improved but still have shortcomings. The core shortcomings focus on four aspects: fabric performance, version design, pressure distribution and movement adaptation.

(4) The comfort performance optimization strategies based on ergonomics are proposed, including fabric selection and modification, version optimization, pressure distribution optimization, etc. All comfort performance indicators of the optimized products have been significantly improved.

AUTHOR CONTRIBUTIONS

Conceptualization –He Xu, Tu Min and Zhou Xiangde; methodology – He Xu, Tu Min and Zhou Xiangde; investigation – He Xu, Tu Min and Zhou Xiangde; writing-original draft preparation – He Xu, Tu Min and Zhou Xiangde. 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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HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Southwest Jiaotong University Hope College, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

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