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Research Article • DOI: 10.2478/ftee-2024-0005 FTEE • 32(1) • 2024 • 40–52

Development and Research on Incontinence Underwear for the Elderly

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Abstract
This study investigates the living conditions of elderly individuals with urinary incontinence and their usage of related products to assess their actual needs, including comfort, convenience, and affordability. Based on these findings, innovative design work was conducted, involving structural design, fabric preparation, and process selection. Ultimately, through product performance evaluation and refinement, the design requirements for comfort, convenience, and affordability were achieved. This research holds significant importance in addressing urinary incontinence issues among the elderly and can be applicable to individuals with restricted access to toilets or those engaged in prolonged activities. Furthermore, the study provides a valuable reference for designing and developing functional garments that cater to practical needs. With further production and market promotion, this research outcome is expected to yield greater value and impact on a larger scale.

Keywords
Elderly with urinary incontinence, comfort, convenience, leakage prevention, incontinence underwear.

1. Introduction

Urinary incontinence is one of the most common chronic diseases among middle-aged and elderly populations. Due to a general lack of accurate awareness regarding urinary incontinence, patients often experience high incidence rates but low healthcare-seeking rates, primarily due to embarrassment and reluctance to discuss the condition openly [1]. Although urinary incontinence does not directly threaten the lives of the elderly, it significantly impacts their physical and psychological well-being and imposes a heavy economic burden on both families and society. Currently, the primary methods available for managing urinary incontinence in the market are disposable hygiene products, such as adult diapers. However, these products are not only bulky and uncomfortable to wear but also contribute to serious environmental harm due to the annual disposal of used diapers [2].

This study conducted extensive research to analyze the actual needs of elderly individuals with urinary incontinence. Based on the physiological and psychological characteristics of the elderly, the development of incontinence underwear specifically designed for this population was undertaken. The aim is to enhance the quality of life for elderly individuals with urinary incontinence, while also aligning with environmental sustainability principles by reducing the environmental pollution caused by disposable hygiene products. Additionally, this research partially alleviates the burden on caregivers.

Currently, elderly urinary incontinence is a well-studied topic within the academic community, with a predominant focus on investigating its underlying causes, pathological aspects, intervention treatments, and the overall impact on affected individuals [3]. Several notable studies have contributed significantly to our understanding of this condition. For example, Batmani et al. conducted a comprehensive global evaluation, providing valuable insights into factors influencing urinary incontinence in elderly women [4]. Chen L. L. and colleagues undertook an extensive review of high-risk factors, aiming to identify and mitigate these factors to reduce the incidence and progression of urinary incontinence and related adverse events [5]. Additionally, Peate I discussed treatment approaches, highlighting the effectiveness of pelvic floor health methods in managing urinary incontinence.

While these studies have greatly enriched our knowledge of elderly urinary incontinence, there exists an unmet need for research that directly addresses the practical needs and living conditions of elderly individuals dealing with this condition. The studies mentioned have primarily centered around etiological and pathological aspects, as well as treatment modalities. However, the day-to-day challenges faced by elderly individuals, such as comfort, convenience, and affordability in managing urinary incontinence, have not received the same level of attention.

Overall, there is limited research focusing on the existing self-management strategies of elderly individuals with urinary incontinence. Currently, the most commonly used products in the market are adult diapers suitable for semi-dependent and dependent elderly individuals, disposable urine collection bags, catheters, and thickened crotch underwear for mild urinary incontinence patients (stress urinary incontinence) [6-9]. Academic research on incontinence underwear is generally limited to the patent stage and lacks direct theoretical research, Researchers from Paul Hartmann AG, C&S PAPER CO., GERSHBAUM, FALKE KGA,

and Ronald Ellingson have conducted studies in which they designed disposable underwear or diapers tailored to urinary incontinence conditions. However, they did not carry out further testing of their performance and usability [10-14].

Therefore, this study focuses on elderly individuals with urinary incontinence and includes the following research aspects: (1) Investigating the current living conditions of elderly individuals with urinary incontinence, analyzing their real needs, and identifying key design points for incontinence underwear. (2) Designing and implementing practical solutions based on research analysis involving structural design, material selection, and process implementation, followed by relevant experiments. (3) Conducting performance evaluations of incontinence underwear through subjective and objective assessments, and making necessary modifications based on the evaluation results. The ultimate goal is to develop functional underwear that truly meets the practical needs of elderly individuals with urinary incontinence, aiming to address the challenges faced by this particular population.

2. Literature Review

2.1. Advancements in Urinary Incontinence Management Methods

Urinary incontinence is a prevalent health concern among the elderly, significantly affecting their quality of life. As early as 1986, Diokno, A. C. and colleagues reported that over 17 million people in the United States suffered from urinary incontinence, with women being twice as likely as men to be affected. The embarrassment and odour associated with urinary leakage can lead to considerable psychological distress and social pressures for elderly individuals [15]. In 2004, Adelmann PK conducted a randomized survey of elderly individuals receiving medical assistance in the United States and examined their medical records. The results showed that 77% of the elderly residents in the 480 nursing homes sampled had urinary incontinence [16]. A survey by Qin, Z. H. and his team among rural elderly individuals in China revealed that few elderly people seek medical attention for urinary incontinence, with only 4.84% receiving treatment, mainly in the form of medication [17]. The prevalence of urinary incontinence among individuals aged 60 and above varies from 5% to 28% for men and 25% to 40% for women, with rates increasing with age [18-19].

To effectively address urinary incontinence in the elderly, extensive research has been conducted to explore and develop management methods. Huang, et al. conducted a literature analysis focusing on research trends in gerontechnology, which provided insights for the design of functional underwear [20]. Melville et al. conducted an epidemiological study among women in the United States investigating the prevalence and impact of urinary incontinence in females [21]. Agarwal and Agarwal studied the prevalence, risk factors, impact on quality of life, and healthcare-seeking behaviour among middle-aged women with urinary incontinence [22]. Elderly individuals employ various coping mechanisms such as using pads, reducing fluid intake, frequent toileting, and avoiding physical activity to manage urinary incontinence [23]. Stickley et al. found an association between urinary incontinence, psychological well-being, and feelings of loneliness in an Irish study involving older adults [24]. Urinary incontinence has significant implications, including social isolation, embarrassment, sexual dysfunction, falls, and infections. Adequate counseling and management can significantly enhance the quality of life for affected individuals [25]. Suhr and Lahmann conducted a representative multicenter study to investigate the prevalence, severity, impact on quality of life, and associated risk factors of urinary incontinence in home care settings [26]. Additionally, Batmani et al. conducted a systematic review and meta-analysis that comprehensively assessed the prevalence and related factors of urinary incontinence in older women globally [27].

These research findings indicate the widespread presence of urinary incontinence among the elderly population and its impact on patients' quality of life. However, challenges and research gaps still exist in the study and design of functional underwear. While Huang et al.'s research provides some insights for product design, specific design requirements and technical details for functional underwear are yet to be clarified. Additionally, progress in research on the disposal and recycling of disposable diapers is lacking [28-29]. Therefore, further research is needed to focus on specific design requirements, material selection, evaluation of urinary incontinence management effectiveness, and other aspects related to functional underwear.

2.2. Advancements in Incontinence Products Research

In the pursuit of effective solutions for addressing urinary incontinence among the elderly population, researchers have explored various innovative approaches. Huang, M.Z. et al. introduced an unconventional approach by employing disposable food storage bags for external fixation in managing urinary incontinence. Their method involves placing the food storage bag over the penis and securing the excess portion near the pubic bone junction. Depending on the material of the bag, it is recommended to change it every 1-2 hours or every 30 minutes [30]. Sun, X.Y. and colleagues designed a novel self-contained urinary catheter system by connecting male/female urinals to a metered, airtight container. This innovative approach allows individuals to manage their incontinence discreetly and independently [31]. Guo, Y.L. and his team implemented an auxiliary pressurization device by implanting a pressure-regulating apparatus (expandable body) into the vaginal canal. This device helps regulate abdominal pressure, reducing instances of urinary leakage associated with increased abdominal pressure [32]. Karram et al. developed a slender tube-shaped device equipped with a pull-

string mechanism designed to control and adjust urethral pressure for urinary incontinence patients. This device provides a customizable solution for managing incontinence [33]. Konno, Shujiro, and colleagues designed and manufactured a disposable and wearable humidity sensor. Using inkjet printing technology, they applied conductive polymer ink to diapers or fabrics. When the relative humidity increases from 35% to 100%, the sensor responds within 42-82 seconds, serving as a notification tool for caregivers [34]. Zou, Y.B. and his team proposed a bowel sound collection system and a semi-supervised generative adversarial network-based defecation prediction method and system. Utilizing network models, they predicted bowel movements based on intestinal sounds. Experimental results indicate an accuracy of 94.4%. While this research offers a novel approach, its applicability to urinary incontinence relief remains limited [35].

These advancements in incontinence product research showcase the diverse strategies being explored to enhance the quality of life for elderly individuals experiencing urinary incontinence. Each approach offers unique benefits and challenges, contributing to the broader quest for improved incontinence management solutions.

2.3. Research Progress on Functional Underwear

The research on functional pants at home and abroad focuses on the study of pants for special populations, such as those with physical disabilities, wheelchair users, and postoperative caregivers, mainly improving the design based on the body shape characteristics of the research object, or researching intelligent pants based on the development of electronic information technology. Wang, Y. F. et al. summarized the materials and technologies used in the current research of adult Urinary incontinence underwear at home and abroad in the Research Progress of Functional Adult Incontinence Pants, and also mentioned the impact of urinary incontinence products on the environment [36]. In their study "Design and Application of Incontinence Care Pants for Coma Patients", Liang, Y.T. et al. modified the crotch structure of an existing patient's clothing based on the inconvenience of nursing patients with urinary and fecal incontinence and lower body paralysis in clinical nursing work, making the improved pants convenient for surgery and care [37]. Wang, L. et al. analyzed the physiological structure and movements of wheelchair users in their article "Functional Improvement Design of Pants for Middle and Elderly Female Wheelchair Users", and mainly made pants structure improvement from the perspective of pants opening and closing methods to address the issue of toilet use for that population [38]. Wang, Y. et al. compared the comfort of commonly used brands of adult diapers in the market and explored the relationship between changes in the microenvironment temperature and wearing comfort of different types of adult diapers through the method of real person trial wear evaluation in "Evaluation of Wearing Comfort of Adult Diapers" [39].

These research advancements in functional underwear demonstrate its significant role in the care and management of elderly individuals with urinary incontinence. The related studies focus on exploring design insights for functional underwear, epidemiological characteristics of urinary incontinence, and the relationship between urinary incontinence, psychological well-being, and quality of life. These studies provide theoretical foundations and practical guidance for the research and design of functional underwear.

3. Research Methodology

3.1. Survey of the Current Status and Market Products for Elderly Individuals with Urinary Incontinence

This study conducted practical surveys to understand the living conditions of elderly individuals with urinary incontinence, the current usage of products, caregivers' perspectives on urinary incontinence products, and the disposal methods of used products. This served as the foundation for the subsequent development of urinary incontinence products. The survey participants, methods, and locations are presented in Table 1.

3.2. Survey Results and Analysis

Urinary incontinence not only affects elderly individuals themselves but also impacts caregivers and the natural environment.

The survey found that urinary incontinence significantly restricts the activity range and content of elderly individuals, preventing them from engaging in outdoor activities like normal elderly individuals. Due to the fear of leakage, elderly individuals frequently visit the restroom, limit their fluid intake, hesitate to go out for extended periods, and even opt to wear dark-colored pants.

Based on the methods of using urinary incontinence products and the manner in which urine is expelled, this study categorized commonly used market products into disposable absorbent products, urine collection containers, and catheters. Disposable absorbent products are convenient to wear but have limited absorbency, are bulky, lack breathability, and are prone to urine leakage. The disposal and recycling of used products are challenging. Urine collection containers are suitable for elderly individuals with better physical conditions but are prone to urine spills and inconvenient to use. Catheters are divided into indwelling catheters and trunk-fixed catheters. The former is generally used by patients and can cause urethral injuries, while the latter has a complex usage process and can cause skin abrasions.

Disposable products like adult diapers on the market have shortcomings in terms of breathability, liquid permeation speed, and leak prevention. Urinals and bedpans are often made of PE material, which

Item	Course Content Operation
Survey Participants	Elderly individuals with urinary incontinence, elderly caregivers, nursing assistants, ward nurses, salespersons, etc.
Survey Methods	Online and offline questionnaires, interviews, observations, photography, audio recordings, etc.
Survey Locations	Nursing homes, hospitals, elderly activity centers, elderly expos, elderly supply stores, supermarkets, etc.

Table 1. Survey of Elderly Individuals with Urinary Incontinence and Related Personnel

can easily cause skin abrasions in elderly individuals and result in urine spills. Urine bags lack breathability and prolonged use can lead to penile inflammation. Therefore, in the design of urinary incontinence underwear, structural design and material selection should aim to ensure dryness, breathability, and comfort during wearing, while allowing easy urination for the elderly.

The survey revealed that over 85% of individuals with urinary incontinence require caregivers' assistance. However, caregivers are unable to promptly determine if elderly individuals with language barriers or sensory impairments have experienced leakage. Some elderly individuals even refuse to cooperate, resulting in urine spills that wet the bed or clothes. This not only affects the physical health of the elderly but also inconveniences caregivers. Therefore, the design of urinary incontinence underwear can incorporate smart alarm systems and simplify the usage process to facilitate caregivers and elderly individuals in changing, removing, and cleaning the underwear.

Elderly individuals have relatively traditional consumption attitudes and are price-sensitive when it comes to products. Even those who are financially capable tend to be frugal and may choose low-quality products in pursuit of lower prices. This is one of the reasons why the market share of domestic elderly diapers is relatively small. However, the quality and hygiene issues of such urinary incontinence products cannot be guaranteed. Therefore, in the design process, a balance should be struck between the functionality and price of urinary incontinence underwear.

Disposable absorbent products are increasing in quantity by billions each year, but the disposal methods usually involve burying, incinerating, or indiscriminate discarding, all of which contribute to secondary environmental pollution or economic issues. Therefore, waste and pollution reduction should be considered throughout the entire design process.

3.3. Design Ideas for Urinary Incontinence Underwear

The unique physiological characteristics of elderly individuals with urinary incontinence determine their higher functional requirements for underwear. In terms of comfort, breathability and leak prevention are the main indicators, and these issues are addressed through urine absorption and drainage methods. In terms of convenience, elderly individuals prioritize easy wearing, simple replacement, and minimal leg lifting or bending. To ensure timely caregiver assistance, a urine wetness alarm device can be added to remind caregivers to perform necessary care tasks. Environmental considerations involve material safety, recyclability, and overall cost control, as shown in Figure 1.

4. Design Practice

Firstly, based on the above design proposals, design experiments were conducted in terms of structure, fabric, and urine wetness alarm device:

4.1. Structure Design

Catheter structure: The catheter is composed of three primary materials: The tubular part is made of silicone rubber, the bag section is constructed from polyethylene (PE), and the inner wall is coated with a silver ion antibacterial layer. The purpose is to guide urine out of the body and keep the elderly person's body dry and comfortable. This study refers to the double layer funnel structure for the design of functional parts of underwear. When standing upright, the liquid is directly exported through the catheter, and when lying down, the liquid will be isolated by the upper funnel to prevent liquid backflow, as shown in Figure 2. The male urethra is long and the direction of urination is not fixed. Therefore, a penis sleeve is provided to separate the penis from the allantois, and connect the Foley catheter with the underpants to ensure that the elderly person will not backflow urine when lying flat, as shown in Figure 3-4. Considering the high prevalence of urinary tract infections among the elderly, the catheter's inner wall was treated with a silver ion antibacterial coating. Additionally, the incontinence underwear underewent antibacterial processing to address this concern.

Catheter connection design: To ensure convenient disassembly of the underwear's urine collection bag without leakage, two options were developed after multiple design attempts. The first option involved embedding the underwear catheter directly into a grooved silicone catheter, securing it with elastic bands, and folding the fabric catheter back and fixing it. Disassembly only requires opening the two elastic bands. The second option employed a slip-resistant adapter, with one end connected to the fabric and fixed with a thermoplastic tube, and the other end fixed to the silicone catheter, allowing for repeated disassembly. Both methods proved to be convenient and leak-proof , shown in Figure 5.

4.2. Fabric Design

4.2.1. Fabric Preliminary Screening

The fabric of urinary incontinence underpants should be soft, comfortable, high elastic, non-irritating, breathable

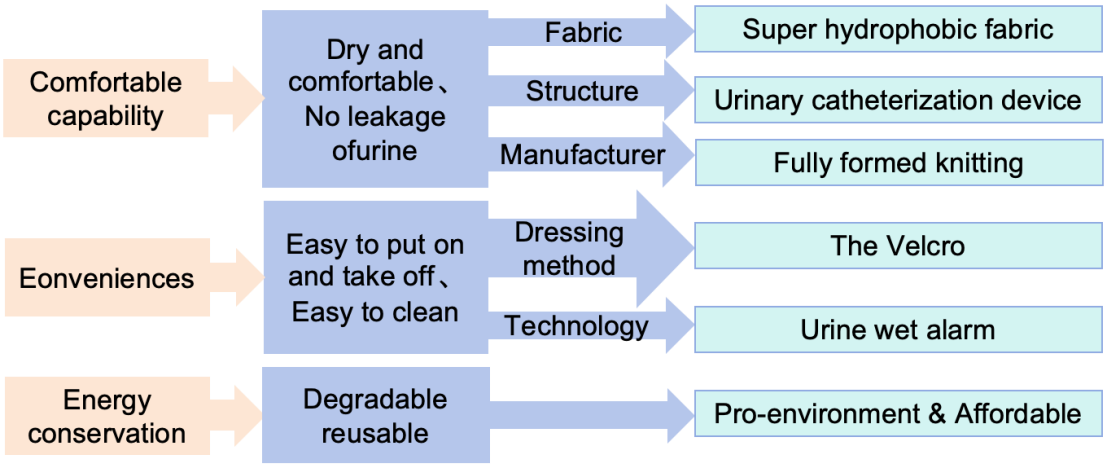


Fig. 1. Urinary Incontinence Underwear Technological Roadmap
Source: drawn by the author

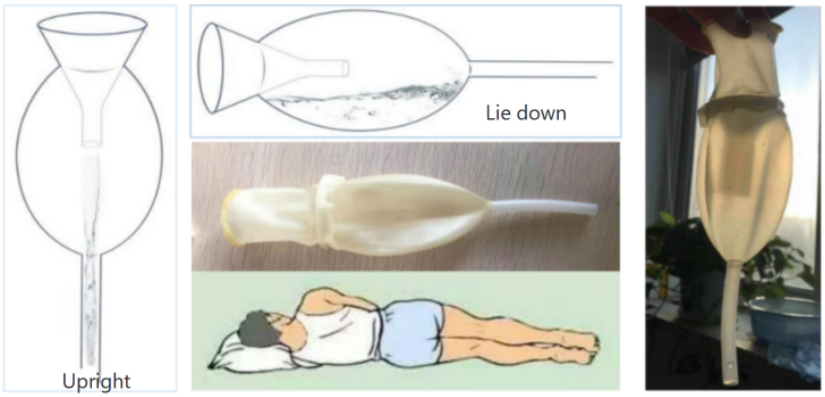


Fig. 2. Double layer funnel structure design (source: drawn by the author and experimental results obtained by the author)

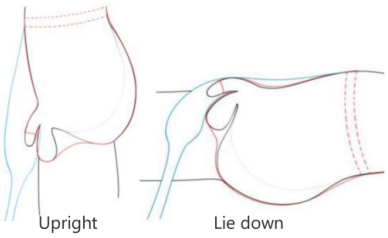


Fig. 3. Functional design diagram of underwear
Source: drawn by the author

Fig. 4. Sample of functional parts of underwear
Source: experimental results obtained by the author

and waterproof for functional parts. This study preliminarily selected fabrics from commonly used underwear fabrics that meet the above characteristics and are suitable for superhydrophobic finishing [40]. After numbering them, superhydrophobic experiments were conducted, as shown in Table 2.

4.2.2. Superhydrophobic Treatment of Underwear Fabric

The superhydrophobic treatment agent used in this study is the fluorinated liquid NuvaN2114lip, provided by Hongcai Feiyang Digital Technology Co., Ltd. in Shishi City, China. The specific experimental process is as follows: (1) the working solution was prepared by mixing the test liquid at a concentration ratio of 30-40 g/L . (2) Adjusting the pH value to 4-5 using a 60% concentration of acetic acid. (3) Soaking and rolling the fabric: soak clean underwear fabric into a solution for 1 minute before removing it. (4) Using an electric, constant temperature blast drying oven, pre-bake at 120-130°C for 5 minutes to evaporate the moisture from the fabric. (5) Baking fabric: bake at 150°C for 3 minutes or 170-180°C for about 35 seconds to crosslink the fabric with the working fluid.

The experimental results, as shown in Figure 6. demonstrated that when water droplets were dropped on the untreated fabric, they were quickly absorbed, whereas the fabric treated with superhydrophobic treatment prevented liquid absorption.

4.2.3. Hydrophobicity and Breathability Testing

The contact angle and rolling angle of the fabric treated with superhydrophobic treatment were measured using a Shanghai KRUSS DSA25 standard contact angle measuring instrument with a 20 μL urine droplet applied using the sessile droplet method. To enhance the rigor of the research, this experiment utilized standardized artificial urine for testing purposes. The air permeability of the fabric was determined using a YG46lH fully automatic air permeability tester at a pressure difference of 100 Pa to calculate the air permeability in mm/s, as shown in Figure 7. Based on the results,

Fabrics	Composition ratio (%) cotton : elastic : polyamide	Organization structure	Mass per unit area (g/m²)
1#	100 : 0 : 0	Weft plain weave	150
2#	95 : 5 : 0	Weft plain weave	170
3#	90 : 10 : 0	Rib weave (R 2/2)	180
4#	80 : 11.5 : 8.5	Weft plain weave	200

Table 2. Specifications of underwear fabric samples for the tests

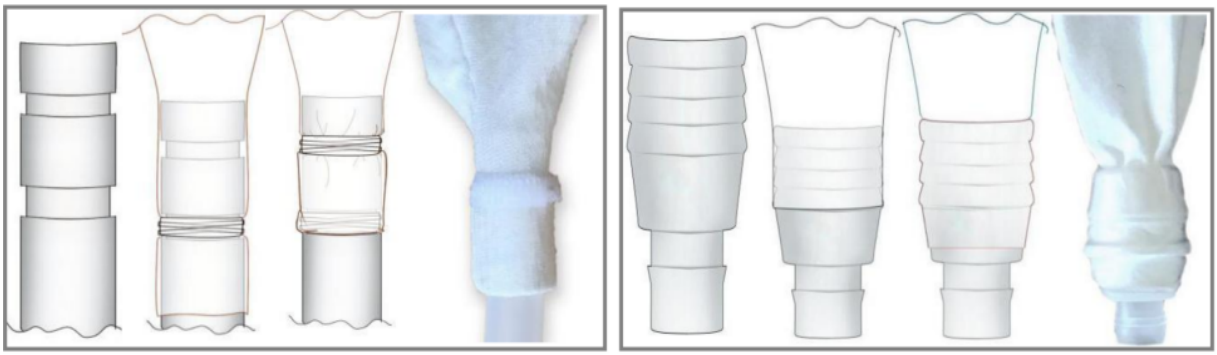


Fig. 5. Design of the two connection modes
Sources: drawn by the author and experimental results obtained by the author

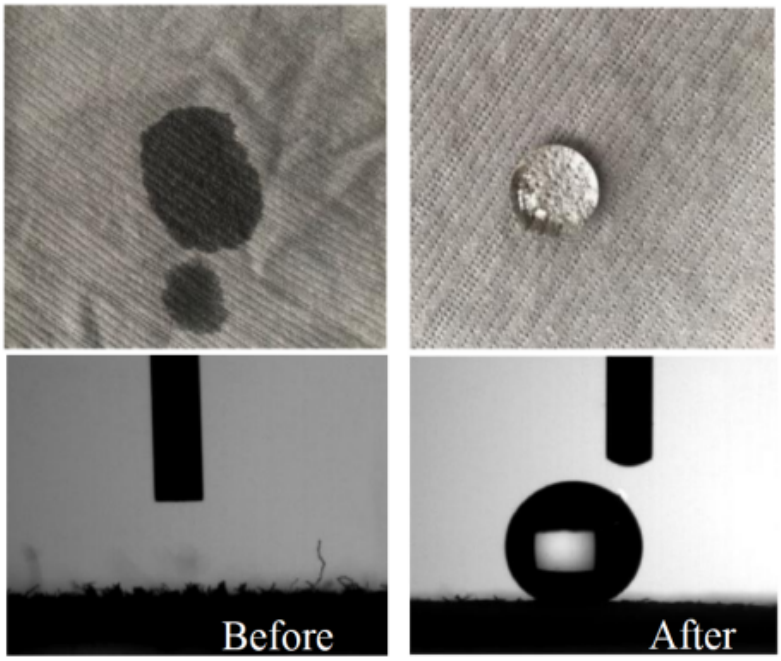


Fig. 6. Comparison of fabric before and after superhydrophobic finishing
Source: experimental results obtained by the author

the fabric that best met the requirements for the underpants in this study was the superhydrophobically treated fabric 3#.

4.3. Intelligent Device

The urine wetness alarm was designed based on the daily nursing needs, using wireless transmission. It consisted of a transmitter and a receiver. The transmitter was used to collect information about urine leakage, while the receiver provided the alarm prompt. When the humidity in the crotch area of the underpants reached 80% [41], the LED and buzzer were activated to remind the caregiver to timely change the diaper. For convenience, the receiver was designed in the form of a badge that could be worn on clothing using a safety pin, making it easy to carry. In this study, the urine wetness alarm was not produced in smaller sizes as it was a small-scale trial product. In the later stages of large-scale commercialization, the size will be reduced to enhance portability, taking convenience into account. Combining with 3D printing technology, a visually simple, comfortable to wear, easy to operate, rechargeable, and wirelessly transmitting moisture-sensitive sensor alarm was finally produced, as shown in Figure 8. In this study, the sensor alarms printed using 3D printing technology employed the Fused Deposition Modeling (FDM) rapid prototyping process with ABS material.

5. Final Development Results

5.1. Incontinence Underpants

Suitable for the majority of male urinary incontinence patients. The first style is a bionic design based on the male physiological structure, which is

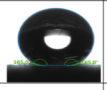
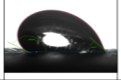
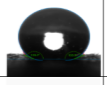
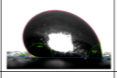
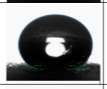
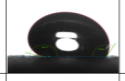
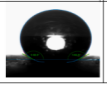
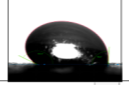
Sample number	Diagram of experimental results	The Number of contact angle	Diagram of experimental results	The Number of rolling angle	Air permeability (before treatment) Unit:L/m2*s	Air permeability (after treatment) Unit:L/m2*s
1#		165.00°		17.60°	974.4	978.8
2#		155.70°		13.23°	324.6	247.5
3#		161.4°		9.75°	483.1	454.6
4#		148.87°		9.85°	131.1	104.6

Fig.7. Hydrophobicity and breathability test results
Source: experimental results obtained by the author

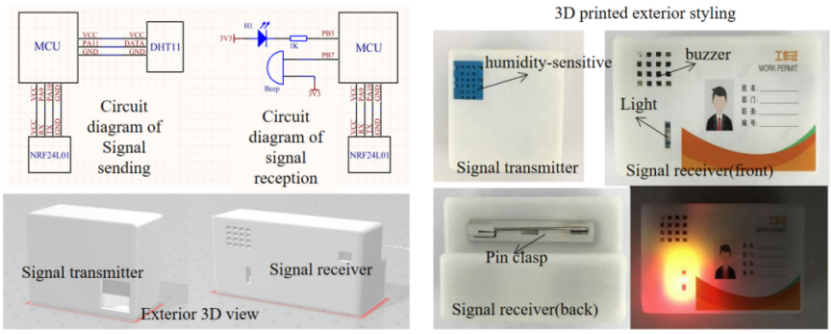


Fig. 8. Urine wetness alarm design
Source: drawn by the author and experimental results obtained by the author

Fig. 9. Style 1: male urinary incontinence underpants
Source: drawn by the author

Fig. 10. Dressing effect of style 1
Source: experimental results obtained by the author

integrated with the diaper and the penis sleeve (when wearing, the penis can be directly inserted into the diaper). The whole style is made of super hydrophobic knitted fabric, which minimizes the seams on the pattern. A one-piece structure is adopted, and TPU hot-melt adhesive is used for stitching to reduce the seam thickness, as shown in Figure 9-10.

Style 2 is to create a penis cover at the front of the underwear to connect it to the underwear, separating the penis from the rest. The outer part of the cover is covered with a diaper bag with a catheter. It is worn in the same way as regular underwear and the elderly man's penis is inserted into a condom. The double-layer structure can effectively prevent urine reflux in elderly people lying flat, as shown in Figure 11-12. The functional parts are made of knitted fabric after superhydrophobic finishing, ensuring basic functionality and comfortable wearing, as well as being economical.

5.2. Alarm-Type Urinary Incontinence Underpants

This product is suitable for incontinence patients who have been bedridden or disabled for a long time. It can be used by both men and women and needs to be paired with diapers. The crotch bottom of the underwear is equipped with a three-dimensional protection against side leakage to prevent urine leakage. The pants are a one-piece structure, and the left and right side seams are fitted with Velcro to achieve a convenient on and off effect. There is a pocket at the bottom of the crotch for storing the information collection terminal of the wireless alarm device, (The underwear fabric is waterproof and breathable, so the collection end can be placed outside the underwear without direct contact with the skin.) When the humidity inside the underwear reaches the set value, a wireless alarm will sound, prompting the caregiver to replace the diaper, as shown in Figure 13-14.

Fig. 11. Style 2: male urinary incontinence underpants
Source: drawn by the author

Fig. 12. Dressing effect of Style 2
Source: experimental results obtained by the author

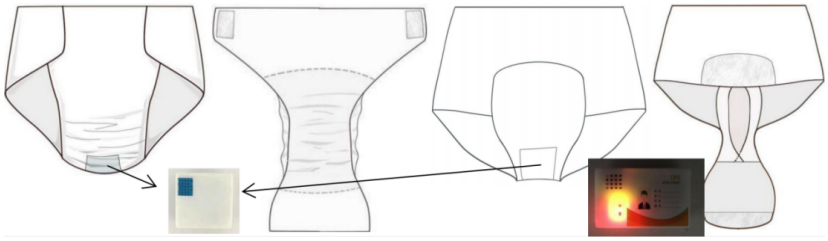


Fig. 13. Rendering of urinary incontinence underwear with alarm
Source: drawn by the author and experimental results obtained by the author

Fig. 14. Dressing effect of urinary incontinence underwear with alarm
Source: experimental results obtained by the author

6. Performance Evaluation of Functional Underpants

Performance evaluation is generally divided into subjective evaluation and objective evaluation, and the results directly reflect the quality of the product. This research took the elderly with urinary incontinence as the research object, and paid more attention to the dressing feelings of the elderly. Therefore, the performance evaluation is mainly subjective, supplemented by objective evaluation to evaluate the performance of the product and improve the scheme.

According to the design requirements, the comfort and convenience of the product shall be evaluated subjectively first, and the comfort of the underwear shall be evaluated by the experience and psychological feeling of elderly with urinary incontinence wearing urinary incontinence underwear in their daily life. The convenience of panties was evaluated through the experience of the operation process of urinary incontinent elderly putting on and taking off and changing their underwear by themselves, the difficulty of helping the elderly to put on and take off and change during the nursing process of urinary incontinent elderly, and the timeliness of changing diapers. Secondly, the overall evaluation and improvement of the underpants' performance are combined with the objective experimental evaluation. Through the experimental data of the hydrophobicity and permeability of urinary incontinence underpants, the objective comfort of urinary incontinence underpants was analyzed and their economy objectively evaluated through the cost accounting of the underpants'

design and production, as well as the purchase and replacement cycle of elderly underpants.

6.1. Evaluation Methods and Indicators

6.1.1. Subjective Evaluation Methods and Indicators

Subjective evaluation quantifies the subjective feelings of users based on the subjective feelings of the evaluator. In this study, five elderly men with urinary incontinence (No. q1-q5) and three nurses (No. q6-q8) were randomly selected for subjective evaluation. Using a psychological scale to establish a sensory scale, the grading points are set at 5, with 5 representing very satisfied, 4 - satisfied, 3 - average, 2 - dissatisfied, and 1 - very dissatisfied. A ruler is marked to obtain the corresponding quantitative values and the relevant data are filled in.

The comfort index of urinary incontinence underpants is mainly dry wearing, with no side leakage or reverse osmosis of urine. The evaluation indicators of convenience mainly reflect the convenience of wearing, changing, and cleaning. The evaluation results will provide an important reference for improving and optimizing the design of incontinence underwear.

6.1.2. Objective Experimental Evaluation Methods and Indicators

In this study, objective experimental evaluation is a supplement to the subjective performance evaluation results. The objective evaluation is based on the design requirements of the comfort, convenience and economy of urinary incontinence underpants. The comfort evaluation index is the permeability and hydrophobicity of the underpants. After every two washes, the urinary incontinence underpants are detected and their numerical changes recorded. The convenience evaluation index is the frequency and steps of changing urine loss underwear; The economic evaluation index is the use cost of urinary incontinence underpants in the cycle.

6.2. Analysis and Revision of Evaluation Results

6.2.1. Subjective Evaluation Results

As shown in Table 3. about the comfort evaluation of urinary incontinence underpants, two elderly people were dissatisfied, and two others thought the comfort was average; because the elderly were too thin, the underpants were not well fitted to the body during wearing, and a small amount of urine leaked. The other four elderly people believed that the urinary incontinence underpants had better comfort and could effectively prevent leakage and lateral leakage. The urinary incontinence products on the market often use plastic buttons, chemical fiber mesh fabric and silicone material to connect the allantois. In contrast, the softness and skin affinity of the urinary incontinence underpants are significantly improved. Moreover, the elderly are more likely to accept incontinence underwear psychologically than devices such as diapers or instruments, which helps restore their self-esteem. In the evaluation of alarm-type underwear, one person felt uncomfortable mainly due to a feeling of foreign objects. The rest of the elderly believed that their condition was not significantly different from that of diapers, but their comfort level was significantly improved.

In terms of convenience, two elderly people were not satisfied with the that of the urinary incontinence underpants, while four elderly people thought the convenience was average, because they thought that the diapers could be thrown away after use, and the underpants needed cleaning (they did not take environmental protection into consideration). The rest of the elderly felt that the urinary incontinence underpants had good convenience, because they do not need to be worn and replaced repeatedly, and the overall convenience was improved. Nurses believed that urinary incontinence underpants simplified the wearing and taking off process and significantly improved the convenience. Alarm style underwear saves more time and care steps.

6.2.2. Experimental Evaluation Results

The incontinence underpants were washed ten times, and the hydrophobicity and breathability were tested and recorded every two washes. The results are shown in Table 4. It can be observed that even after ten washes, the hydrophobicity of the urinary incontinence underpants remained in a state where the static contact angle was greater than 150° and the rolling angle was less than 10°, and there was minimal change in breathability. This indicates that the incontinence underpants maintain good wearing comfort even after multiple washes.

A comparison was made between urinary incontinence underpants and urine receiving products commonly used in nursing homes, the results of which are shown in Table.4. In terms of wear and tear frequency, urinary incontinence underpants only need to be replaced once a day, while other products need to be replaced several times according to the number of times the elderly use the toilet. Urinary incontinence underpants are slightly higher than for paper diapers when they are put on and off for a single time, because urinary incontinence underpants need to be connected with a Foley catheter, urine collection bag and other matching products; but the total time consumption is far lower than for other products. The results further verified the convenience of urinary incontinence underpants.

As shown in Table 5. the price of urinary incontinence underpants is 25 yuan/ piece, and each pair of underpants can be used at least 10 times (i.e. 10 days), while the price of 10 day diapers is about 126-200 yuan. Compared with disposable diapers, incontinence underpants have

Evaluation indicators \ Participant ID		q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	q11
Incontinence underpants	Comfort	4	3	2	3	4	2	4	4	-	-	-
	convenience	2	4	3	3	4	3	3	2	4	5	5
Alarm-type underwear	Comfort	3	4	3	2	4	3	4	3	-	-	-
	convenience	3	4	4	4	3	3	4	4	5	3	5

Table 3. Subjective evaluation results

Number of washes	Contact angle (deg)	Rolling angle (deg)	Transpiration rate (mm/s)
0	161.4	9.75	454.6
2	162.1	9.66	456.1
4	161.1	9.75	455.5
6	161.1	9.68	454.0
8	160.8	9.83	460.6
10	158.6	10.00	462.2

Table 4. Comfort evaluation experiment

Item	Urinary incontinence underpants	Diapers	Urinals	Seat urinals
Wearing and taking off frequency	1 time/day	6-8 times/day	8-10 times/day	6-8 times/day
Wearing time	200 s	180 s	70 s	320 s
Stripping time	85 s	48 s	50 s	120 s
Total time	285 s	1368s-1824s	960s-1200s	2640s-3520s
Price	¥25	¥1.8-2.5	¥5-15	¥40-50
Daily average price		¥12.6-20		
10 day average price	¥25	¥126-200		
Urinary leakage	NO	NO	little	little

Table 5. Evaluation of convenience and economy

obvious advantages. At the same time, it also reduces the labor burden of nurses in the nursing process, as well as the follow-up cost of waste diaper disposal.

7. Discussion

7.1. Advantages of Urinary incontinence underpants

This study aimed at the practical difficulties of urinary incontinent elderly in their daily life to carry out the design and development of urinary incontinence underpants. Compared with traditional underpants and urinary incontinence products, their leak proof design solved the leakage problem of common Urinary incontinence products through the anti-backflow structure and anti-side leakage structure, ensuring dry and comfortable wearing of the underpants. The connector design solves the problem of urine leakage when replacing underpants or urine collection bags, and also provides favorable conditions for the reuse of urinary incontinence underpants. At the same time, the urine humidity prompt device can timely remind nurses to replace the urine humidity products, which not only saves the use cost but also nursing industry human and financial expenditure. The superhydrophobic underwear fabric has the characteristics of softness, breathability, hydrophobicity, and biodegradability, providing comfort for the elderly while reducing negative impacts on the environment. Therefore, incontinence underpants have obvious advantages in comfort, functionality and economy, making them a feasible choice to solve the problem of urinary incontinence in the elderly.

7.2. Further Optimization Plan

Although this study provides detailed information on the design of Urinary incontinence underpants, there are still some problems that need to be further studied and solved: first, the size and adaptability. Different elderly people and other users may have different figures and sizes, so how to ensure that urinary incontinence underpants can meet the needs of different groups of people is a question to be discussed. The second is user feedback and improvement issues. In the subjective evaluation stage, this study evaluated the incontinence underpants according to the subjective feelings of the elderly with urinary incontinence and nurses to verify the functionality of the product. However, does a broader user survey need to be conducted to obtain more comprehensive

user feedback? By collecting user feedback, the design can be further improved and optimized to meet a wider range of needs and increase user satisfaction. The third issue is market promotion and acceptance. The study mentioned that once the product matures and is mass-produced, it will be pushed onto the market and realize its value. However, in addition to technical and performance considerations, market research and discussion of promotion strategies are also needed to ensure that the product can be widely recognized and adopted.

Therefore, although this study provides a detailed design scheme and application prospects, there are still some issues that need further discussion and research. By conducting in-depth research on these issues, the design quality and practicality of functional underwear can be further improved to meet a wider range of user needs.

8. Conclusion

8.1. Main Findings of the Study

First of all, this study investigated the elderly, nurses and related products on the market, and found that the elderly Urinary incontinence as a whole had a high incidence rate and low medical treatment rate. They dealt with Urinary incontinence by using disposable diapers, urinals and other products, and were very dissatisfied with the products currently used. They hoped that Urinary incontinence underpants would be comfortable, convenient, and economic.

Secondly, the study conducted design analysis based on research findings, following the principles of comfort, convenience, and economy. In terms of structure, design has been carried out from the aspects of anti-backflow structure, anti-side leakage structure, and urinary tube connection structure. In terms of material selection, after screening and superhydrophobic finishing of commonly used underwear fabrics, the optimal hydrophobic and breathable underwear fabric was determined through experiments. In terms of craftsmanship, taking into account the special needs of elderly people in clothing production, a suitable craftsmanship method was selected, and a wet underwear alarm device was designed for severely disabled elderly people. Finally, the design and production tasks were completed.

Then, through subjective evaluation and objective experimental evaluation, the study established an evaluation index system for Urinary incontinence underpants and conducted performance evaluation. The evaluation results show that the Urinary incontinence underpants designed in this study meet the design requirements of comfort, convenience and economy.

In addition, the results of this study are not only applicable to the elderly with Urinary incontinence, but also applicable to those who work for a long time or are not convenient to go to the toilet due to environmental restrictions, such as medical staff, astronauts and drivers who drive for a long time during the epidemic, which has certain universality and value.

8.2. The Potential Value of Urinary Incontinence Underpants

With the development of the aging society, Urinary incontinence underpants will become a necessity of the times. The needs of the elderly with Urinary incontinence will also become more diverse. The design of Urinary incontinence underpants is not the ultimate goal. The ultimate goal is to better meet the needs of the elderly and improve their quality of life through continuous optimization of product design and performance. Therefore, the continuous research and development, promotion, and application of functional underwear require the joint efforts of all sectors of society. Governments, enterprises, research institutions, and social organizations can collaborate to promote the development of elderly care, jointly promoting sustainable development and enhancing market competitiveness.

8.3. Limitations of the Study

This research has achieved some results in various aspects, but it also faces certain limitations. Firstly, the number of participants in the survey needs to be increased to enhance the representativeness and breadth of the research findings. The conclusions drawn at present are not definitive and should be regarded as preliminary findings, serving only as a reference for further research and practice. Secondly, the design and functional details of the urine wetness alarm require deeper investigation and optimization to better meet the actual needs of the elderly. Additionally, the age range of the respondents needs to be expanded to ensure that the research outcomes comprehensively cover elderly individuals of different age groups. In summary, although this study has provided valuable insights into the development of incontinence underwear for the elderly, further research is needed to overcome these limitations and better serve this demographic.

Acknowledgements

This paper was financially supported by the scientific research achievements of the National Experimental Teaching Demonstration Center for Fashion Design and Engineering (Dalian Polytechnic University) and the Fund Project of Science and Technology Project of Jiangxi Provincial Department of Education (GJJ202417).

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