Journal of Fiber Bioengineering and Informatics 19:1 (2026) 31–50

Cite as: Y. Ru et al.
doi:10.3993/jfbim26003

A Case Study on the Physical and Psychological Health Design Requirements of Postoperative Female Breast Cancer Patients

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Abstract

While existing rehabilitation products for breast cancer survivors primarily focus on compression therapy, they often neglect the integrated physical and psychological needs of patients, leaving a critical gap in holistic home-based care. Therefore, this study integrates Quality Function Deployment (QFD) and the Theory of Innovative Problem Solving (TRIZ) to systematically address this gap. Through a questionnaire survey and expert evaluation, patient requirements were gathered, prioritized, and translated into design specifications using QFD, while TRIZ was employed to resolve technical contradictions among them. Based on these findings, an exploratory rehabilitation apparel system is proposed that integrates an adaptive structure, functional materials, embedded hardware for physiological monitoring, and an interactive platform. Potential validation approaches are outlined to assess its safety, functionality, and practical implications in future research.

Keywords: Breast cancer; Apparel design; Health; Quality Function Deployment; Theory of Innovative Problem Solving

1 Introduction

Breast cancer is a prevalent disease among women, with approximately 300 000 new cases diagnosed annually in China [1]. Unfortunately, breast cancer treatment often involves procedures such as breast removal, hair loss, chronic pain from medication side effects, and negative psychological effects such as self-abasement, anxiety, and annoyance [2], thereby experiencing significant dual burdens. Following hospital discharge, patients typically require long-term rehabilitation care, which is predominantly conducted at home. In hospitals, treatment and nursing care for postoperative female breast cancer patients are highly professional. However, rehabilitation at home can be challenging due to the lack of proper guidance and devices for the disease. Currently, the most common method for postoperative female breast cancer patients to rehabilitate at home is compression therapy, which involves using either compression bandaging or compression apparel

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Mar. 2026

for breast cancer-related lymphedema [3]. Compression bandaging can cause bandage displacement during breast compression, impaired upper extremity function, and respiratory discomfort if compression is excessive [4]. Compression apparel avoids these issues but may not reduce lymphedema volume as effectively due to improper compression, and it is inconvenient for patients to put on and take off themselves [5]. It can be noted that while compression bandaging and compression apparel are often used for physical rehabilitation after breast cancer surgery, they have the aforementioned disadvantages and do not allow for smart control of compression, which can lead to reduced lymphedema volume [6]. Moreover, current compression therapy focuses solely on physical rehabilitation. Still, mental counseling is also important for postoperative breast cancer patients who often experience pressure and negative emotions when they return home after treatment due to a lack of professional support. While existing research has extensively explored the breast geometry of healthy populations to inform the design of foundational apparels such as sports bras and personalized bras [7-10], and has explored smart textiles for early breast cancer detection [11], there remains a significant gap in addressing the specific rehabilitation needs of postoperative female breast cancer patients. These patients require not only apparel that accommodates their altered anatomy but also integrated solutions for physical therapy and psychological support.

To address these challenges systematically, user requirements must be accurately translated into product design specifications. Quality Function Deployment (QFD) enables systematic translation of user requirements into design objectives through its House of Quality (HoQ) tool [12]. However, while QFD identifies contradictions among design requirements, it lacks tools for resolving them. The Theory of Inventive Problem Solving (TRIZ) provides systematic methodologies for generating innovative solutions by transforming negatively correlated requirements into technical contradictions and applying 40 Inventive Principles [13]. The integration of QFD and TRIZ ensures design directions align with user requirements while systematically addressing technical contradictions [14].

The integrated application of QFD and TRIZ has exhibited remarkable value in the design of rehabilitation assistive devices. Simarmata et al. [15] combined QFD, TRIZ, and AHP to develop 3D-printed insoles for flat-foot patients, optimizing the structural design via TRIZ to reduce plantar load and improve wearing comfort. Yu et al. [16] integrated improved QFD and TRIZ to design a hand spasticity assessment exoskeleton, thereby realizing the dual diagnosis-and-treatment functions of rehabilitation robots. Hung et al. [17] adopted the QFD-TRIZ integration method to optimize the design of general and Parkinson's disease-specific walkers, respectively, resolving design conflicts to elevate user satisfaction. Xi et al. [18] developed a QFD-TRIZ integrated model for wheelchair design for the elderly with disabilities, balancing user demand satisfaction and product technical feasibility. These studies collectively confirm that the QFD-TRIZ integration method effectively guides the innovative design of rehabilitation assistive devices to meet diverse user needs.

Despite this progress, research has focused mainly on motor impairments, offering limited guidance for products addressing the combined physical and psychological needs of postoperative female breast cancer patients. While notable work exists on general bra design for specific populations [19] and smart textiles for cancer detection [11], these studies do not address the complex design contradictions inherent in rehabilitation apparel that must simultaneously deliver therapeutic compression, monitor physiological data, and support mental well-being. Therefore, a research gap exists in the systematic design of rehabilitation apparel that addresses both the physical and psychological needs of postoperative breast cancer patients, particularly in resolving

the inherent technical contradictions among therapeutic compression, physiological monitoring, and psychological support functions. To address this gap, this study integrates QFD and TRIZ to systematically translate these dual needs into design specifications, resolve technical contradictions, and generate a conceptual rehabilitation apparel featuring adjustable compression and psychological support.

2 Method

The research framework integrating QFD and TRIZ is illustrated in Fig. 1, comprising four main stages: user requirements acquisition, Quality Function Deployment (QFD), Theory of Inventive Problem Solving (TRIZ), and design validation. The process begins with user requirements acquisition, where a questionnaire survey collects patient needs, followed by expert evaluation and scoring to determine the relative importance of each requirement. Subsequently, in the QFD phase, prioritized user requirements are translated into design requirements. A House of Quality is constructed to establish the relationship matrix between user and design requirements and to calculate design requirement weights. The HoQ analysis further reveals negative correlations among design requirements, which are then addressed in the TRIZ phase. In the TRIZ phase, these negative correlations are transformed into engineering contradictions using the 39 engineering parameters. The contradictions are resolved by applying the 40 inventive principles and 4 separation principles, generating an innovative design solution. Finally, the proposed design solution is verified.

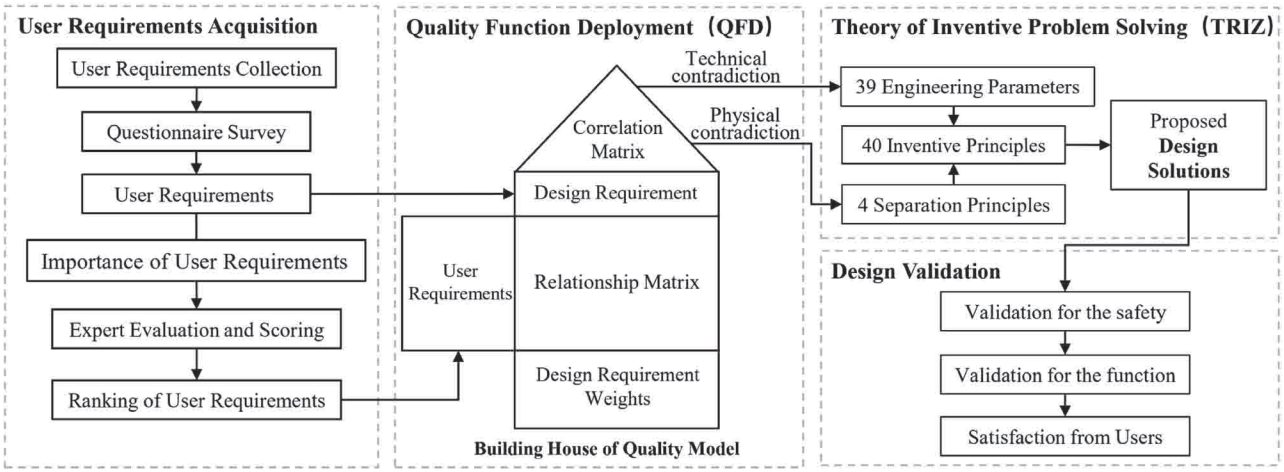

Fig. 1: QFD and TRIZ-based design framework

2.1 User Requirements Acquisition

2.1.1 User Requirements Collection

User requirements are typically gathered through questionnaires. The questionnaire comprises a series of single-choice questions designed to elicit information regarding user needs and is administered to a large sample of respondents.

This study targeted postoperative female breast cancer patients in Southwest China. Data were collected over three months via an online questionnaire accessible at https://www.wjx.cn/vj/tYXLv5y.aspx. The questionnaire covered various aspects of postoperative female breast cancer patients, including their personal information, symptoms, complications, therapy, rehabilitation needs, mental impacts, and preferences for digital health technologies. A total of 521 responses were received. After excluding invalid questionnaires, the remaining responses were used to derive the initial set of patient requirements.

2.1.2 Importance of User Requirements

To determine the relative importance of user requirements, experts in the relevant field of product design were consulted. A cutoff threshold of 0.7 for Cronbach's coefficient alpha and 0.4 for the item-total correlation coefficient [20] was established.

Ten experts specializing in apparel design and medicine, recruited from companies, universities, and hospitals, were invited to participate in the study. They were first asked to review the collected requirements and categorize them into similar groups [21]. To determine the importance of these requirements, the same group of experts was then asked to rate them using a 5-point Likert scale. The ratings were processed in SPSS, and Cronbach's alpha and item-total correlations were calculated to assess internal consistency reliability. Patient requirements with a Cronbach's coefficient alpha below 0.7 or an item-total correlation below 0.4 were removed [22]. The mean scores for the remaining patient requirements were then calculated, and their rankings were established, with higher scores indicating greater importance.

2.2 Quality Function Deployment (QFD)

2.2.1 Define Design Requirements

To address the important user requirements identified in section 2.1.2, a team of experts was consulted to identify design features based on their domain knowledge. This process allows for capturing design requirements that respond to user requirements. Subsequently, the experts engage in a second round of discussions to refine and finalize these design requirements.

2.2.2 Building the House of Quality Model (HoQ)

The establishment of the "User Requirements-design Requirements" HoQ is based on the refined user requirements and design requirements from previous steps. The interrelationships among design requirements are depicted on the roof of the HoQ (Fig. 2), with the symbol "+" indicating positive relationships and "-" indicating negative relationships. A positive relationship indicates that improving one design requirement also enhances another, whereas a negative relationship indicates that improving one design requirement adversely affects another [23]. The correlation between user requirements and design requirements can be captured in the HoQ, and is represented by a rating scale (0-1-3-5) corresponding to four levels of correlation strength (none, weak, medium, and strong). The importance of design requirements can be determined by calculating the correlation score, using the following equation:

$$I_j = \sum_{i=1}^{m} K_i R_{ij} \quad (i = 1, 2, 3, 4, \cdots, m) \tag{1}$$

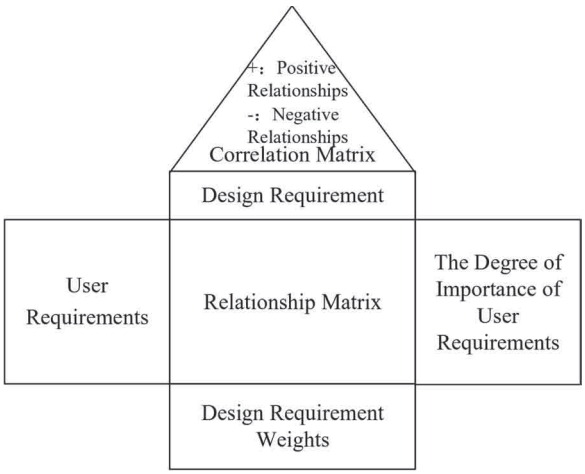

Fig. 2: QFD House of Quality Model

where I_j represents the importance score of the jth design requirement, K_i represents the mean score of the ith user requirement as obtained from section 2.1.2, and R_{ij} represents the correlation score between the ith user requirement and the jth design requirement.

2.3 Theory of innovation problem solving (TRIZ)

2.3.1 Translating into Technical Contradictions

The negative relationships between design requirements derived from HoQ were transformed into technical contradictions by using 39 Engineering Parameters of TRIZ (Table 1).

Table 1: 39 Engineering Parameters

1. Stress or pressure	21. Power
2. Shape	22. Loss of Energy
3. Stability of the object's	23. Loss of substance
4. Strength	24. Loss of Information
5. Duration of action by a moving	25. Loss of Time
6. Duration of action by a stationary object	26. Quantity of substance/matter
7. Temperature	27. Reliability
8. Illumination intensity	28. Measurement accuracy
9. Use of energy by moving object	29. Manufacturing precision
10. Use of energy by a stationary object	30. External harm affects the object
11. Weight of moving object	31. Object-generated harmful factors
12. Weight of a stationary object	32. Ease of manufacture
13. Length of moving object	33. Ease of operation
14. Length of a stationary object	34. Ease of repair
15. Area of a moving object	35. Adaptability or versatility
16. Area of a stationary object	36. Device complexity
17. Volume of moving object	37. Difficulty of detecting and measuring
18. Volume of a stationary object	38. Extent of automation
19. Speed	39. Productivity
20. Force	

2.3.2 Contradiction analysis and resolution

There are two types of contradiction: physical and technical. A physical contradiction arises when conflicting requirements or characteristics exist within a problem. On the other hand, a technical contradiction occurs when an improvement in one system parameter leads to a deterioration in another. These contradictions can be resolved by applying the 40 Inventive Principles of TRIZ, which are categorized into four categories of separation principles: separation of opposite requirements in space, separation of opposite requirements in time, separation within a whole and its parts, and separation based on conditions, as demonstrated in Table 2 [23].

3 Result

The results obtained from the integrated QFD and TRIZ methodology described in Section 2 identify the key patient requirements and design contradictions for rehabilitation apparel for postoperative female breast cancer patients. The main analytical outcomes include the prioritized patient requirements, the design requirements derived from the House of Quality analysis, the technical contradictions identified through TRIZ, and the corresponding inventive principles applied to resolve them.

3.1 Patient Requirements

3.1.1 Identified and Prioritized Patient Requirements

As shown in Table 3, 16 patient requirements were identified and grouped into four categories: physical therapy, psychological, interactive, and wearing.

The importance of patient requirements was determined through expert ratings. After removing requirements that did not meet the reliability thresholds (Cronbach's $\alpha < 0.7$ or item-total correlation < 0.4), the mean scores and standard deviations (SD) for the remaining requirements were calculated, and their rankings were established with results presented as mean $\pm$ standard deviation, as shown in Table 4. It is important to clarify that Table 3 presents the full spectrum of patient needs identified through the initial questionnaire, categorized by domain. In contrast, Table 4 reflects only those requirements that passed the statistical reliability threshold and were rated as most critical by experts. However, during the subsequent QFD and TRIZ integration process, lower-ranked requirements were not simply discarded. Instead, they were often indirectly addressed as supporting features of higher-ranked design requirements, or reintroduced through inventive principles as complementary solutions to technical contradictions. This ensures that the final design remains both user-centered and technically holistic.

3.2 Quality Function Deployment Results

3.2.1 Design Requirements

Based on the expert conversion of patient requirements into design requirements, 7 design requirements were identified, as shown in Table 5. It is noted that the requirements for "Mobile

Table 2: Separation Principles corresponding to 40 Inventive Principles of TRIZ

Types	The number of 40 inventive principles
1. Separation of opposite requirements in space	1. Segmentation 2. Taking out 3. Local quality 4. Asymmetry 7. "Nested doll" 13. "The other way round" 17. Another dimension 26. Copying 30. Flexible shells and thin films 40. Composite materials
2. Separation of opposite requirements in time	9. Preliminary anti-action 10. Preliminary action 11. Beforehand cushioning 15. Dynamics 16. Partial or excessive action 18. Mechanical vibration 19. Periodic action 20. Continuity of useful action 21. Skipping 29. Pneumatics and hydraulic 34. Discarding and recovering 37. Thermal expansion
3. Separation within a whole and its parts	12. Equipotentiality 28. Mechanics substitution 31. Porous materials 32. Color changes 35. Parameter changes 36. Phase transitions 38. Strong oxidants 39. Inert atmosphere 40. Composite materials
4. Separation upon condition	1. Segmentation 5. Merging 6. Universality 7. "Nested doll" 8. Anti-weight 13. "The other way round" 14. Spheroidality-curvature 22. "Blessing in disguise" or "Turn Lemons into Lemonade" 23. Feedback 24. "Intermediary" 25. Self-service 27. Cheap short-lived objects 33. Homogeneity 35. Parameter changes

Table 3: Female patient requirements

Physical therapy requirements	1. Compression therapy 2. Drug replacement 3. Compression controllability 4. Compression fixation 5. Smooth breathing
Psychological requirements	6. Mental health care 7. Rehabilitation communication forum 8. Emotional expression
Interactive requirements	9. Mobile phone interactive platform control 10. Health monitoring data visualization 11. Health warning 12. Doctor-patient communication 13. Professional rehabilitation guidance 14. Exercise supervision
Wearing requirements	15. Fabric comfort 16. Apparel aesthetics

Table 4: Rank of female patient requirements

Rank	Female patient requirements	Mean score ± SD	Item-total correlations > 0.4	Alpha if Item deleted > 0.7
1	Compression therapy	4.32 ± 0.84	0.583	0.803
2	Mental health care	4.30 ± 0.95	0.603	0.835
3	Drug replacement	4.25 ± 0.70	0.621	0.738
4	Fabric comfort	4.21 ± 0.63	0.537	0.764
5	Mobile phone interactive platform control	4.16 ± 0.57	0.482	0.852
6	Smooth breathing	4.08 ± 0.74	0.530	0.796
7	Doctor-patient communication	4.05 ± 0.77	0.609	0.719
8	Apparel aesthetics	4.01± 0.82	0.517	0.832

phone interactive platform control" and "Doctor-patient communication" can be consolidated into a single design requirement, namely "Develop a more comprehensive system".

3.2.2 House of Quality Analysis

The HoQ for postoperative breast cancer patient apparel design was constructed and is presented in Fig. 3. The relationships between the design requirements at the top of the HoQ revealed three pairs of negative relationships. These relationships resulted in the identification of three key contradictions, which serve as innovative problems: (1) How to resolve the conflicting requirements of "Simple compression therapy" and "Material suitability"? (2) How to resolve the contradiction between "Material suitability" and "Develop a more comprehensive system"? (3) How to resolve

Table 5: Design requirements

	Female patient requirements	Design requirements
1	Compression therapy	Simple compression therapy
2	Fabric comfort	Material suitability
3	Drug replacement	Easy-to-wear
4	Smooth breathing	Stable and firm
5	Apparel aesthetics	Overall appearance structure
6	Mobile phone interactive platform control Doctor-patient communication	Develop a more comprehensive system
7	Mental health care	Hardware monitoring equipment

the conflict between "Overall appearance structure" and "Hardware monitoring equipment"?

The importance scores of the design requirements, as depicted in Fig. 3, were calculated using equation (1) in Section 2.2.2. The scores indicate the level of importance of each design requirement, with higher scores indicating greater importance. From the ranking of the design

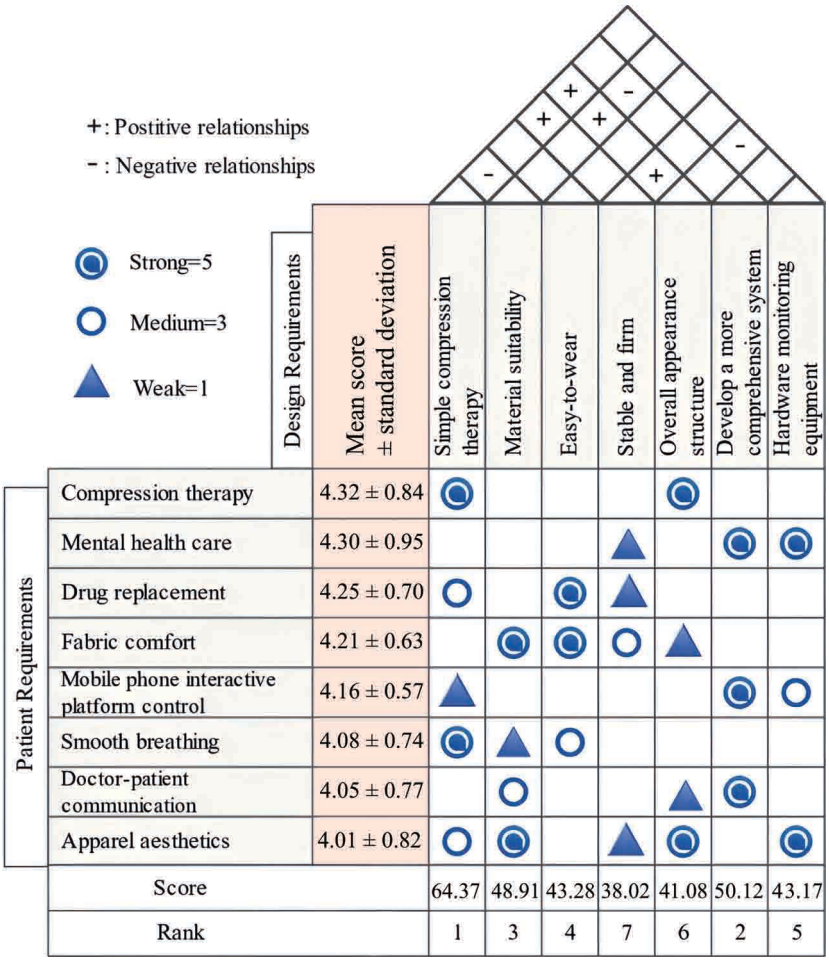

Fig. 3: House of Quality diagram

requirements, "Simple compression therapy", "Develop a more comprehensive system", "Material suitability", "Easy-to-wear", "Hardware monitoring equipment", and "Overall appearance structure" were found to be more important design requirements for apparel product design for postoperative female breast cancer patients.

3.3 Theory of Innovation Problem Solving Analysis Results

3.3.1 Identification of Technical Contradictions

In terms of the 39 Engineering Parameters of TRIZ discussed in section 2.3.1, the three contradictions identified in section 3.2.2 were mapped to the corresponding Engineering Parameters, as shown in Table 6. These contradictions were further categorized as either physical or technological contradictions based on TRIZ.

Table 6: The design parameters and types of technical contradictions

	The contradictions	Engineering Parameters	Types of technical contradictions	Separation Principles corresponding	Inventive principles
1	"Simple compression therapy" and "Material suitability"	11. Stress or pressure 33. Ease of operation	Physical contradiction	Separation of opposite requirements in space	3. Local quality 40. Composite materials
2	"Material suitability" and "Develop a more comprehensive system."	35. Adaptability or versatility 37. Difficulty of detecting and measuring	Technology contradiction	Separation upon condition	23. Feedback 24. Intermediary
3	"Overall appearance structure" and "Hardware monitoring equipment"	32. Ease of manufacture 36. Device complexity	Technology contradiction	Separation upon condition	5. Merging 6. Universality

3.3.2 Resolution of Contradictions

According to the separation principle shown in Table 2, the 40 Invention Principles of TRIZ discussed in section 2.3.2 were applied to solve the above contradictions. For the first technical contradiction and its associated engineering parameters, as shown in Table 6, the material properties can be adjusted to enhance compression therapy, indicating that this contradiction is physical in nature. Accordingly, the Separation Principles related to spatial separation were employed to address the contradiction. The recommended Inventive Principles for this problem are No. 1, No. 2, No. 3, No. 7, No. 13, No. 17, No. 24, No. 26, No. 30, and No. 40, as listed

in Table 2. Considering the limited location of wounds in postoperative female breast cancer patients, it is proposed to implement compression therapy only in the affected area using Inventive Principle No. 3 (Local Quality). The design will involve incorporating an inflatable airbag in the specific location of the postoperative breast cancer wound to achieve compression therapy by considering the engineering parameter of pressure. This design will be realized in the product structure section of the apparel. In addition, Inventive Principle No. 40 (Composite Materials) was used to improve the comfort and durability of the fabric used in the apparel product, and it involves developing a variety of fabric designs and structural designs that meet the engineering parameters of ease of operation. This design aspect will be implemented in the material section of the apparel product. Thus, the first technical contradiction was successfully resolved using the TRIZ methodology.

The second and third technical contradictions, along with their corresponding engineering parameters, are purely technical. The recommended Inventive Principles for addressing these contradictions are No. 1, No. 5, No. 6, No. 7, No. 13, No. 14, No. 22, No. 23, No. 24, No. 25, No. 27, No. 33, and No. 35, as listed in Table 2. To address the second technical contradiction between material suitability and the development of a comprehensive system, hardware devices were integrated into the apparel fabric to enable health monitoring. Inventive Principles No. 23 (Feedback) and No. 24 (Intermediary) were utilized to transmit the patient's health data to the App interaction platform. To address the third technical contradiction between the overall appearance structure and the hardware monitoring equipment, Inventive Principles No. 5 (Merging) and No. 6 (Universality) were used to select the hardware and determine its placement within the apparel product to ensure feasibility. Consequently, hardware was embedded within the apparel structure to monitor patient health metrics and transmit the data to the interactive platform, applying the principles of Feedback and Intermediary. The design aspect will be implemented in the hardware section. Furthermore, the interactive interface was developed in accordance with the principles of Merging and Universality to address patient needs and complete the design of the interactive health monitoring system. This design aspect will be implemented in the interactive platform section. Thus, the second and third technical contradictions were successfully resolved using TRIZ.

4 Discussion

The results obtained from the integrated QFD and TRIZ analysis can provide a systematic basis for translating patient requirements into potential design solutions for rehabilitation apparel for postoperative female breast cancer patients. Based on the contradictions identified and resolved in Section 3, a conceptual design solution can be developed. The following sections discuss how these findings may be translated into specific design components, including the apparel structure, material selection, embedded hardware, and the interactive platform. In addition, potential validation approaches are outlined to evaluate the safety, functionality, and user satisfaction of the proposed system.

4.1 Design Solution

Based on the solution of the technical contradiction principle outlined in section 3.3.2, this study has developed a design to improve apparel products for postoperative female breast cancer pa-

tients, focusing on the product's structure, materials, hardware, and interactive platform.

4.1.1 Apparel product structure

In Fig. 4, the apparel product structure was designed as a hanging-neck style with partial airbags, which provided good encapsulation of the breasts and prevented displacement of the compression by the airbags, as discussed in section 3.3.2. The one-piece structure included six independent airbags: two on each left and right breast and four on the left and right armpits. The airbags on the left and right breasts were circular to avoid pressing the wound around the papilla and squeezing the exudate in the breasts from the wound [24]. The other four airbags on the armpit were designed to address wounds that extended to the armpit, and they could also squeeze the exudate in the armpit [25]. Each airbag contained an inner high elastic sponge and two valves on its surface (Fig. 5). Opening the inflation valve allows air to enter, causing the sponge to expand rapidly. Once the desired pressure is achieved, the valve can be closed to maintain compression. The deflation valve controlled deflation, and the airbag pressure could increase it. These six independent airbags allowed for localized compression, which was beneficial for a patient's specific condition and avoided compressing the entire chest, including the healthy breast. Additionally, the remaining part of the apparel product had ample space to accommodate hardware. Patients can easily put on and remove the apparel product themselves, and the front-zip design makes drug replacement convenient.

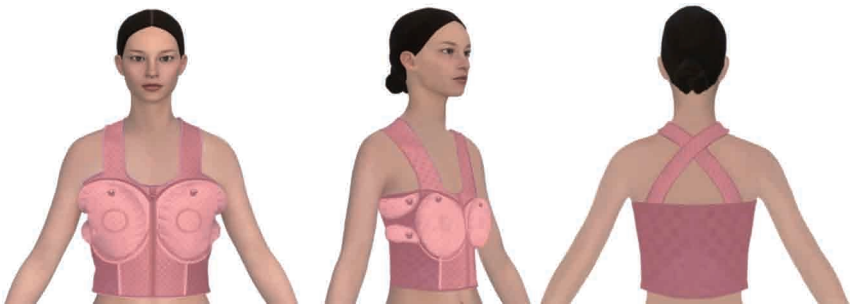

Fig. 4: Apparel product for postoperative female breast cancer patients

4.1.2 Apparel product material

As apparel comes into contact with the skin, material selection should prioritize comfort. Accordingly, fabrics with softness, breathability, and high elasticity were selected. As shown in Fig. 5, the outer layer of the apparel product used Lycra fabric to improve its extensibility and elasticity, ensuring ease of movement for patients of different body sizes. The innermost layer was made of absorbent cotton fabric, which could absorb exudate from the wound. Additionally, the airbag's materials included highly elastic sponge bonded with two layers of PVC, while the front zipper is made of a skin-friendly resin.

4.1.3 Hardware

In accordance with the health monitoring principles established in section 3.3.2, wearable devices are mainly used to monitor the patient's heart rate, blood pressure, temperature, and interface

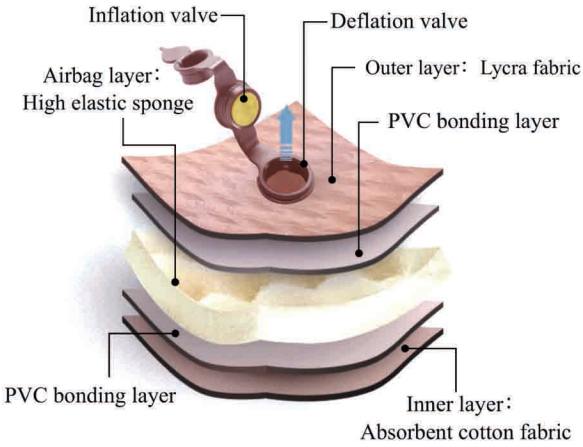

Fig. 5: Fabric composition

pressure between the body and the devices. The hardware consisted of four modules: the power supply module, data acquisition module, data processing module, and data transmission module. The power supply module provided power to the other modules. The data acquisition module incorporates wearable sensors placed in direct contact with the patient's body to measure heart rate, blood pressure, temperature, and interface pressure. The data processing module analyzed and processed the data collected by the data acquisition module and uploaded the processed data to the interactive platform through the data transmission module (Fig. 6). To minimize the impact of the hardware on dressing comfort, the devices used in this design were lightweight, small in size, and high-performance. They were concealed in two small pockets inside the apparel product (Fig. 7). Details of each module's design are described below.

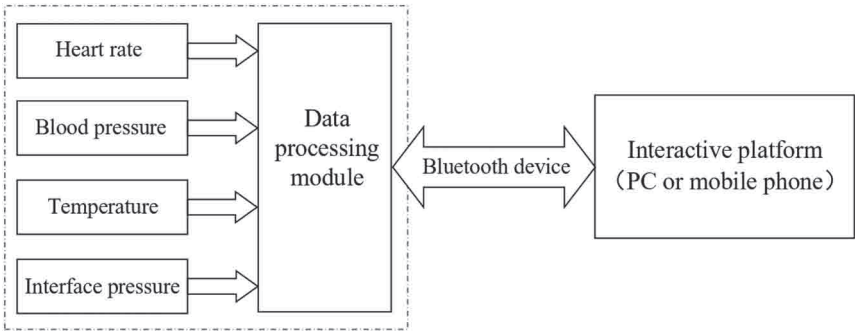

Fig. 6: Design scheme of modules for the apparel product

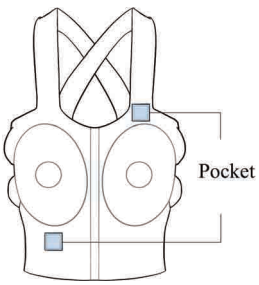

Fig. 7: Pocket position on the apparel product

The power supply module used an LG flexible-cable battery with high specific capacity, good flexibility, and cyclic stability, while remaining lightweight. For heart rate monitoring, the Neurosky BMD101 sensor was used [26], which was comfortable to wear, easy to operate, and included a 1.2V voltage regulator and diode electrostatic protection. The blood pressure sensor used the Yunkear MKB0705 intelligent wearable monitoring module [27], known for its efficiency, stability, and long-term dynamic blood pressure monitoring capability. To collect body temperature data, the 14J20 flexible NTC temperature sensor was used, which had good flexibility and a suitable size and could effectively monitor fever symptoms associated with incisional infection [28]. In addition, the Pico-Press®pneumatic pressure measurement system was intended to be incorporated into this design to accurately control the interface pressure between the wearable device and the body and to prevent postoperative lymphedema fluid [29]. The STM32F103C8T6 microcontroller was selected for the data processing module due to its compact size and good cost-performance [30]. The data transmission module used the SPP-C Bluetooth device [31], which was designed for intelligent wireless data transmission, suitable for transmitting physiological data, and compatible with the interactive platform. The distribution of hardware on the apparel product is shown in Fig. 8.

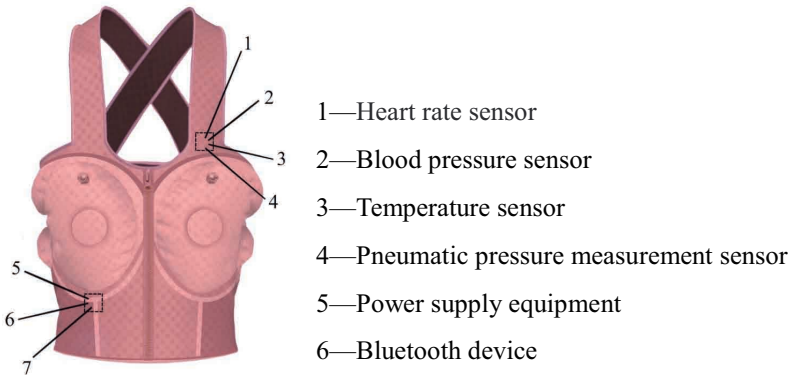

Fig. 8: Devices distribution

4.1.4 Interactive platform

In accordance with the principles of Merging (No. 5) and Universality (No. 6) in section 3.2.2, an interactive mobile application platform was designed. The interactive platform received data from the hardware via Bluetooth and displayed real-time, readable data for postoperative female breast cancer patients and caregivers. If a patient's heart rate, blood pressure, temperature, or interface pressure was abnormal, the app would send an alarm. Furthermore, the platform generates longitudinal monitoring reports, enabling patients and clinicians to better understand physiological trends and optimize nursing care. Beyond real-time monitoring, home-based exercise is recognized as an essential component of breast cancer rehabilitation. However, due to a lack of awareness and professional guidance, exercise efficiency was usually low, and the risk of wound dehiscence increased. Therefore, the interactive platform included a doctor-patient communication module, a rehabilitation exercise punch module, and other modules to provide professional guidance and supervise a patient's home exercise.

To further address patients' psychological needs, the platform also includes a peer-support forum and a digital diary-writing module. These features provide access to educational resources

on breast cancer, foster a supportive community for peer encouragement, and offer an outlet for emotional expression, collectively contributing to improved mental well-being. Although requirements such as the "Rehabilitation communication forum" and "Health warning" did not rank among the top eight in the expert importance evaluation (Table 4), they were reintroduced during the TRIZ-based design phase as complementary features. Specifically, the rehabilitation communication forum was developed as an extension of the "Mental health care" requirement (Rank 2), using the TRIZ principle of Merging (No. 5) to combine psychological support with social interaction. The health warning function was integrated as part of the "Develop a more comprehensive system" design requirement (Rank 2 in design importance) and is enabled by the TRIZ principle of Feedback (No. 23), which enhances patient safety through real-time alerts. This demonstrates how lower-ranked user needs can be transformed into valuable design elements through systematic innovation methods, ensuring that the final product addresses both statistically prioritized and contextually essential requirements. A detailed overview of the modules within the interactive platform is presented in Fig. 9.

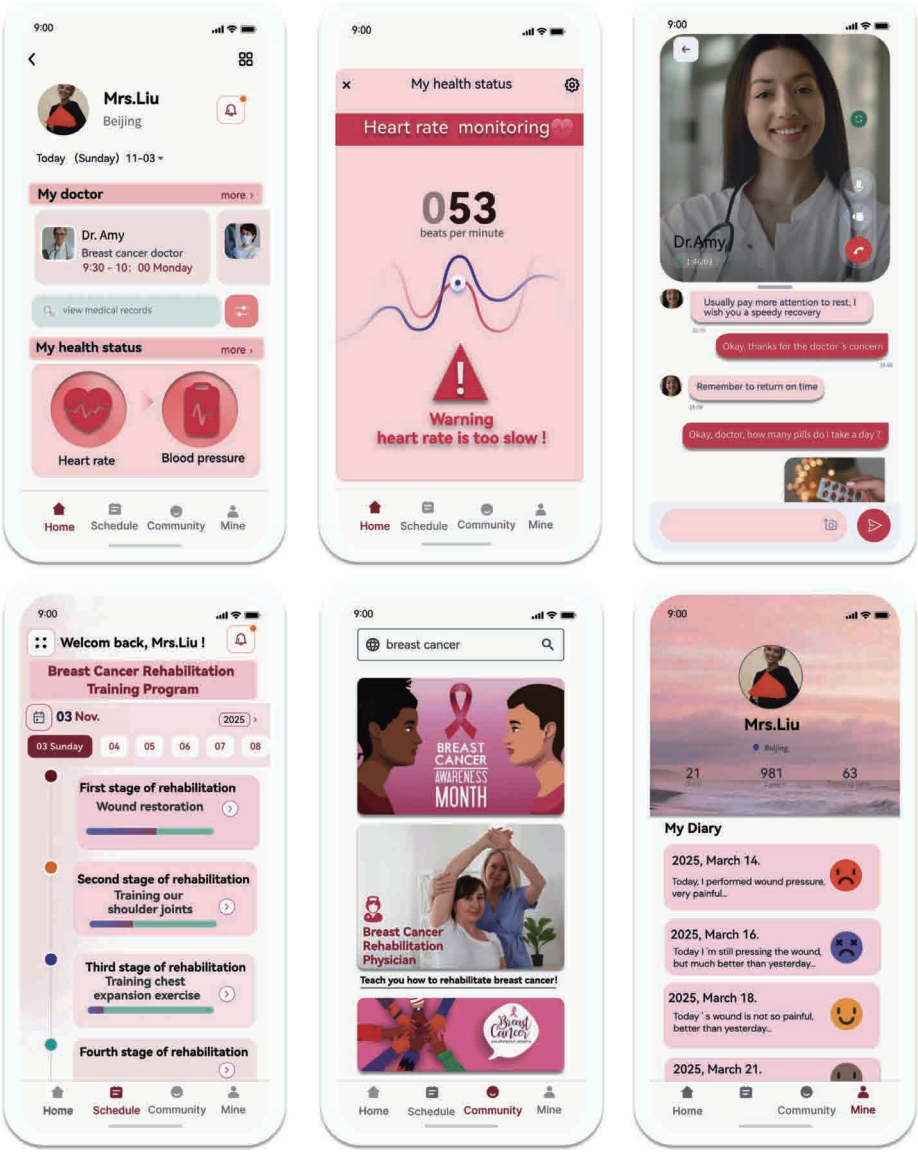

Fig. 9: Modules displayed on the interactive platform

4.2 Design validation

The validation of the conceptual design of an apparel product with digital health technology for postoperative female breast cancer patients comprises three aspects: safety, functionality, and patient satisfaction. The overall validation scheme is in Fig. 10.

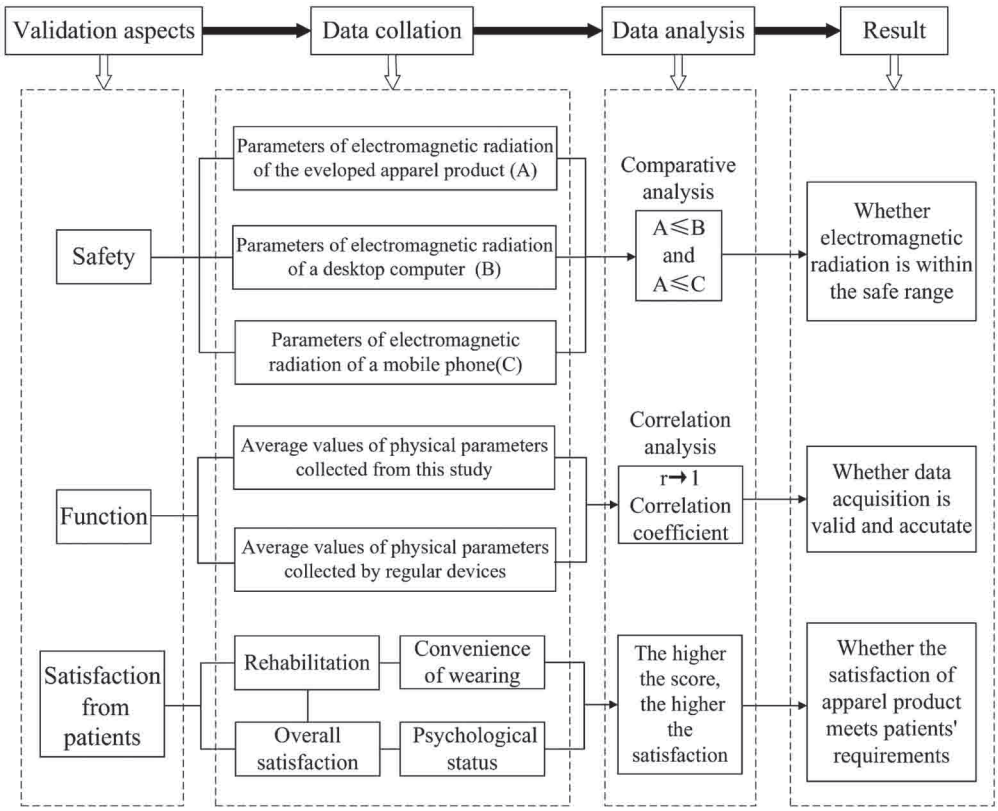

Fig. 10: Diagram of validation scheme

4.2.1 Validation for the safety

Safety validation primarily involves verifying that the electromagnetic radiation emitted by the wearable devices integrated into the apparel product remains within safe limits. A test setup will be established using an electromagnetic radiation detector to measure the radiation parameters of the developed apparel product, a desktop computer, and a mobile phone. To minimize measurement errors, all reference devices must be from the same brand. The electromagnetic radiation parameters of the developed apparel product will be compared with those of the desktop computer and mobile phone. If the radiation levels of the apparel product are equal to or lower than those of the reference devices, this will indicate that the product's electromagnetic emissions fall within the safe range, thereby supporting its suitability for collecting patient physiological data (Fig. 10).

4.2.2 Validation for the function

Functional validation aims to ensure that the data collected by the hardware devices is both valid and accurate. The validation procedure comprises the following steps. First, a cohort of

postoperative female breast cancer patients will wear the developed apparel, and an experimenter will record their heart rate, blood pressure, body temperature, and interface pressure for 30 minutes using the mobile application. For each patient, the mean values of these parameters will then be calculated. Subsequently, the experimenter uses regular devices, such as an ECG monitor, mercury thermometer, and manometer, to record the same parameters for each patient's heart rate, blood pressure, body temperature, and interface pressure three times, and calculates the average values. Finally, a correlation analysis will be performed between the two data sets. A correlation coefficient approaching 1 would indicate a strong linear relationship between the measurements obtained from the smart apparel and those from the reference devices, thereby confirming the validity and accuracy of the data acquired by the developed product (Fig. 10).

4.2.3 Satisfaction from patients

To evaluate patient satisfaction, a future user study will invite a sample of postoperative female breast cancer patients to use the developed apparel for a specified period and then complete a survey via the mobile app. To ensure assessment rigor and validity, the survey will integrate custom product-specific items with established psychometric scales across three dimensions: physical comfort and usability, psychological well-being, and perceived usefulness and acceptance. Physical comfort and usability will be assessed through custom questions on fabric comfort, ease of donning/doffing, and convenience of the compression adjustment mechanism, rated on a 5-point Likert scale. Psychological well-being will be measured using the World Health Organization-Five Well-Being Index (WHO-5) [32], a validated self-report instrument with five positively worded items rated on a 6-point Likert scale; this scale aligns with the study's "Mental health care" priority (Rank 2, Table 4) and provides standardized emotional state assessment. Perceived usefulness and acceptance will be evaluated by adapting selected items from the Technology Acceptance Model (TAM) questionnaire [33], focusing on "Perceived usefulness" and "Perceived ease of use" to determine whether the digital health features are genuinely helpful and user-friendly from the patient's perspective. All items are rated on Likert scales, with higher mean scores per dimension reflecting greater satisfaction. Optional open-ended questions will be included to gather qualitative insights, and this mixed-methods approach will ensure a comprehensive understanding of user experiences.

5 Conclusion

In this paper, an integrated QFD and TRIZ methodology was applied to address the complex design challenge of creating rehabilitation apparel for postoperative female breast cancer patients that meets both their physical and psychological needs. Through the application of QFD, key patient requirements were identified and prioritized, which were subsequently translated into design specifications. The subsequent TRIZ analysis identified inherent technical contradictions among these specifications, including those between therapeutic compression and material comfort, and between integrated hardware and aesthetic form, and corresponding inventive principles were applied to address them. Based on these analytical outcomes, a conceptual rehabilitation apparel system was developed that integrates adaptive structural elements, functional materials, and digital health technologies.

The main contributions of this study are as follows:

(1) A conceptual framework integrating QFD and TRIZ is presented to systematically translate the dual physical and psychological needs of postoperative breast cancer patients into design specifications and to address the inherent technical contradictions.

(2) A conceptual rehabilitation apparel system is proposed, integrating adaptive structural elements, functional materials, and digital health technologies, which offers a potential approach to home-based rehabilitation by combining physical therapy support with psychological care features.

As the current findings are derived from a conceptual and exploratory design, further empirical validation, including functional testing and clinical user studies, will be necessary to assess the feasibility and effectiveness of the proposed system.

Acknowledgement

The authors wish to acknowledge financial support from the Fundamental Research Funds for the Central Universities (2050205-01).

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