

Research on Integrated Design of Hardware and Software for Needle-Free Insulin Injection Systems for the Elderly

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Abstract: With the accelerating trend of global population aging, the incidence of diabetes among the elderly continues to rise. Insulin injection, as one of the key methods for treating diabetes, has disadvantages like high operation difficulty and poor compliance among elderly patients in actual application. This research conducts in-depth investigations on the characteristics of elderly diabetic patients, identifying key difficulties they experience in using needle-free insulin injection products. On this basis, a design solution covering overall interaction reconfiguration and function optimization is proposed, with needle-free insulin injectors as the core to develop an integrated support system tailored for the elderly. Results demonstrate that this optimized design exhibits significant effectiveness in enhancing the device experience of elderly patients and improving compliance. The innovation of this research lies in approaching the needle-free injection issue from an overall medical-patient perspective, providing a new solution strategy to meet elderly diabetic patients' device needs, with extensive potential for promotion and application.

Keywords: Needle-free insulin injection, Elderly diabetic device needs, Integrated elderly assistive device.

1. Introduction

The world has stepped into an aging society. With the growth of age, the elderly's demand for medical care gradually increases, especially the treatment of chronic diseases like diabetes, which has become a major challenge for them and seriously affected their quality of life [1]. The number of diabetic patients worldwide has exceeded 460 million, of which over 25% are elderly patients over 60 years old, showing an upward trend every year. Insulin injection is one of the common methods to treat diabetes. For elderly diabetic patients, needle-free injection products reduce the pain caused by conventional injections and eliminate the need to repeatedly use needles, thus having potential advantages in improving treatment compliance [2]. However, considering the general decline in cognitive and operating abilities of the elderly, the usability of existing products needs further research, providing research opportunities to improve elderly diabetics' needle-free insulin injection experience.

Based on the specific physical and mental characteristics of the elderly and the actual demands of needle-free insulin injection products, this research adopts a human-centered design philosophy, comprehensively discusses the matching between products and users, products and environment, aiming to achieve an optimization scheme with strong targeting, easy operation and easy promotion. In addition, the discussion of design philosophy and technical means is to improve treatment compliance of elderly diabetic patients, alleviate medical pressure, and promote the application of needle-free injection devices in a wider range and scenes, which is of great social significance.

2. Literature Review

2.1. Current Status of Insulin Injection Products for the Elderly

With the continuous development of medical science and technology, the insulin therapy methods for diabetic patients have been continuously optimized, from initial simple syringes, to later insulin-specific syringes, insulin pens and needle-free injectors. Each improvement enhanced operational convenience and reduced painful use. Among current insulin injection products, insulin-specific syringes, pens, and needle-free injectors are used in parallel. However, these products have seen relatively smaller changes in structural and morphological designs with similar style lines. Their functional optimization and technical upgrade speeds are relatively slow, making it difficult to keep up with the times. Although some products have intelligent assistive functions, they overemphasize the injection technology itself without providing comprehensive intelligent support throughout the user's entire life cycle [3-4].

When these products are used by the elderly, due to the lack of full consideration of the target group's cognitive and motor characteristics, their compliance and treatment experience need further improvement [6]. Therefore, it is necessary to redesign from an overall medical-patient perspective, use information technology to achieve integration between needle-free injection devices and supporting systems, fully consider various human-machine interaction links to realize integrated injection operation, data statistics and health management, thereby effectively improving safety injection experience and compliance for elderly diabetic patients.

Table 1. Categories of Insulin Injection Products

Product Type	Representative Products	Main Features
Insulin-specific syringes	Owen Mumford Autopen	Insulin-specific syringes have a simple structure and are economical and practical; however, single-use needles require configuration which is cost-effective yet needs certain skills for repeated configuration
Insulin pens	NovoPen 6	Insulin pens feature a pen design that facilitates carrying; pre-loaded insulin cartridges can be reused, thus reducing configuration steps and making them more user-friendly
Needle-free insulin injectors	Fiasp FlexTouch	Needle-free insulin injectors do not require repeated puncturing injections so they are painless and traceless, but are relatively bulky overall and demand higher operation skills

2.2. Design Principles for Needle-Free Insulin Injectors for the Elderly

With the intensifying population aging trend in China, the incidence of chronic diseases among the elderly continues to rise. The demand for needle-free insulin injection products in the elderly population has become increasingly prominent. In such context, the importance and urgency of designing needle-free insulin injection products for the elderly group is gradually emerging. However, through literature research and market research, it is found that existing products still have certain deficiencies in key quality indicators such as safety, ease of use and comfort. This further emphasizes the necessity of differentiated customization and optimized design based on the cognitive and physiological characteristics of the elderly.

In discussing the design concepts of needle-free insulin injection products, safety, ease of use, and comfort have become indispensable key quality indicators. First of all, regarding the basic quality indicator of safety, considering the gradual decline in physiological functions and cognitive levels among the elderly, ensuring product safety should be the primary principle and strict prerequisite of the design. This requires not only high stability and reliability of internal structures, but also achievement of smooth outer shapes and corners to realize zero risks [7]. In addition, clear audio and visual prompts are critical to eliminate safety hazards caused by reduced perception or insight. Second, ease of use should also be regarded as a key indicator and priority factor of product design. On the basis of ensuring reliable basic practical functions and operation techniques, the cognitive and memory burdens on elderly users should be reduced. Through overall intelligent assistance and considerate humanized design details of the products, it can be made simple and intuitive enough for the elderly. Thus, the elderly can easily get started and reduce operation difficulties to improve product satisfaction during use [8]. Finally, comfort

should also run through the entire design process. This includes not only smooth and stable injection and operation experiences, soft and gentle material feels, but also the overall product atmosphere and colors that can help generate positive and uplifting emotions [9]. Together they can help reduce the psychological burden on elderly patients and improve product compliance.

In summary, in order to meet the needs of elderly groups for needle-free insulin injections, designers should fully pay attention to product safety, ease of use and comfort, based on the physiological and psychological characteristics of the elderly, and carry out differentiated customization and optimization. By improving product quality and user experience, the elderly can feel care during treatment and improve their quality of life. In future market competition, needle-free insulin injection products with high-quality and humanized designs will be more competitive and provide better medical services for China's elderly population.

3. Methodology

3.1. Research Framework

In order to efficiently implement the design research of needle-free insulin injection products, the research team carefully formulated a reasonable and feasible design process and methods. In the design research stage, the team thoroughly analyzed the market status and user needs of similar domestic and international products, in order to clarify the shortcomings of existing products and potential optimization directions, and set goals for subsequent innovative designs. Next, in the design innovation stage, the team conducted in-depth research into the product issues discovered from multiple perspectives such as visual effects, human-computer interaction, and product performance. It aims to solve the problems users encounter in actual use through technological and formal optimizations. Finally, in the scheme implementation stage, after fully verifying the feasibility and implementation difficulty of the scheme, the team validated and optimized the design concepts through prototype production and testing to ensure that the product can still meet user needs after conversion. Through the iterative cycles of the three stages, the research team is committed to creating more sophisticated needle-free injection products to provide more efficient and convenient treatment experiences for diabetic patients. The practice of this design process also provided valuable references for the design and R&D of similar medical products in China.

3.2. Problem Analysis

Through investigations and analysis, it was found that most elderly patients did not receive adequate instructions when using existing injection devices. The choices of injection timing and sites were unsatisfactory, thus affecting treatment effectiveness. At the same time, repeated use of needles increased risk of infection. For elderly patients with declining self-care abilities, they often find it difficult to adapt to and master operations of conventional syringes and exhibit apparent fear emotions. These issues highlight that existing injection methods failed to fully consider special needs of the elderly population.

On the other hand, although existing needle-free injection devices are advanced drug delivery tools and should improve the above problems to a large extent, it was found that the operational convenience and user experience of such devices

for elderly patients need to be enhanced. Specifically, the cartridge replacement process is complicated with limited support types; compared to insulin pens, needle-free devices have larger sizes and weights which are not conducive to operation; lacking feedback on medicine release makes it difficult for elderly users to judge efficacy on their own; separating injections for different types of insulin also increases usage frequency and time. These factors indicate that the designs of needle-free devices failed to fully meet practical needs of elderly patients. Therefore, implementing differentiated customized designs and optimizations has become an inevitable choice to alleviate anxiety among elderly users and improve compliance.

4. Design Practice

4.1. Design Positioning

Preliminary research shows that current needle-free injection devices, due to not fully considering characteristics of the target elderly group, lead to issues like complicated operations and reduced compliance in application scenarios with elderly patients. Therefore, this research aims to develop a highly customized intelligent needle-free injection solution for the elderly. While maintaining the advantages of needle-free techniques, this product focuses on reducing operational difficulty in a targeted manner and enhancing product applicability for the elderly. Specifically, measures such as simplifying cartridge replacement procedures, customizing grip structures, adding medicine release feedback will be adopted, so that the entire injection management process becomes more convenient, painless and proactively supportive. This will eventually assist elderly patients in smoothly completing treatment, ensuring efficacy, and enable them to enjoy better experiences in the enhancement of usability.

4.2. Product Logo Design

The product is named "Nuoshou", containing dual meanings of "NO SUGAR" and "commitment to a comfortable life", aiming to bring users a more comfortable experience. A matching LOGO is also designed (as shown in Figure 1).



Figure 1. Product Logo Design

4.3. Product Modeling and Functional Design

This research adopts smooth curved surface modeling to highlight intelligent and automated concepts. The exterior proportions of the product follow the golden ratio principle, using green as the main tone, presenting a technological style. The product functions include two modes: blood glucose

measurement and insulin injection. The upper display shows blood glucose values in real time; the middle has insulin adjustment buttons; the lower part is used for skin contact to measure blood sugar and implement insulin injections (as shown in Figure 2). Meanwhile, to facilitate patients and individuals to view measurement data, a matching WeChat mini program is designed for users, focusing on both user experience and enhancing technological level of the product.



Figure 2. Product Rendering Design

5. Conclusion

This research puts forward a promising elderly-centered needle-free injection solution, applying human factors principles to streamline the injection process and address user emotions. While the motivation to overcome existing limitations through human-centered design is laudable, further validation would significantly enrich this work's academic value and real-world influence. Specifically, clinical studies demonstrating improved treatment adherence over time among elderly patients could provide compelling evidence of the research's human-centered merits.

To further elevate its contributions, detailed discussion and data illuminating the specific user experience advances from emotional design and integrated optimization are recommended. Exploring scalability across user groups and disease applications would underscore broader relevance. Addressing limitations and detailing next stages stand to strengthen this study as the basis for ongoing innovations. With these enhancements in scientific rigor and impact, this research could readily meet leading publication standards, advancing human-centered injection solutions from foundational evidence to transformative outcomes.

Acknowledgment

This work was made possible with the support of the Program of Xinmiao Potential Talents in Zhejiang Province, which provided financial support for the subject study (2023R452004).

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