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Design of Intelligent Anti-Snoring Sleep Pillow Based on QFD-KANO Model in the Context of Consumption Upgrading among Urban and Rural Residents

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Abstract

By using a questionnaire survey method to understand and explore user needs, combined with the QFD-KANO model to quantify research results, and using the "Better Worse coefficient" statistical method, the survey results are transformed into design practices. In the design practice, technologies such as sensors, signal processing, and control systems were adopted to achieve precise recognition and intelligent control of snoring sounds. The test results show that the intelligent anti snoring sleep aid pillow can achieve a snoring recognition accuracy of 94%, with high reliability and stability.

Keywords

KANO Model, Intelligentization, Snoring Sleep Pillow

1. Introduction

In the context of upgrading consumption in urban and rural areas, there have been profound changes in the living standards and consumption concepts of residents in our country. People are no longer content with merely meeting their survival needs; they increasingly seek personalized and high-quality life experiences. As urban and rural residents pursue a higher quality of life, their attention to health and comfort has grown, further promoting the rise of smart health products. This study employs the QFD-KANO model to investigate smart anti-snoring sleep pillows, aiming to understand user needs and expectations for anti-snoring products. QFD begins with user needs and translates them into specific characteristics of product design, thereby enhancing the understanding of market demand. Meanwhile, the KANO model focuses on analyzing user satisfaction with product features, providing profound theoretical guidance for product design.

2. Market Research Based on QFD-KANO Model

2.1. Introduction to the QFD Model

The QFD model is a research method for product design and production that originated in Japan [1]. It converts user and market needs into accurate data, providing precise guidance for various stages of product design and production. In corporate implementation, the QFD model helps reduce wasted design time, minimize time lost due to changes in design proposals, streamline design and manufacturing costs, and improve product quality. By meeting users' diverse needs, companies can enhance customer satisfaction and strengthen the competitiveness of their products [2].

However, the QFD model also has some limitations. Its development originated in Japan, which may pose adaptability issues when applied in different cultural and management contexts, particularly in Western companies. The effectiveness of QFD relies on accurate market research; any errors or inaccuracies in market research can severely impact subsequent analysis and decision-making processes. In the current rapidly evolving market environment, where user demands change quickly, and the difficulty of conducting market research increases. As a systematic management tool, the complexity of QFD may present challenges for companies during implementation, requiring significant resources for learning and application.

2.2. Introduction to the KANO Model

The KANO model was proposed by Japanese professor Noriaki Kano in the 1980s. This model analyzes project requirements from two perspectives: the adequacy of the requirements and the users' subjective perceptions. It establishes a nonlinear relationship between user satisfaction and the adequacy of requirements, categorizing user needs into five types: attractive needs, expected needs, must-be needs, indifferent needs, and reverse needs [3]. The KANO model enhances product service quality characteristics to meet user demands, categorizing product requirement characteristics and observing their trends of change.

2.3. Advantages of Using the QFD-KANO Model in Combination

The combined use of the QFD-KANO model leverages the strengths of both models effectively. The application of the KANO model provides a solid foundation for initial market analysis by deeply exploring user expectations for anti-snoring products, intricately depicting the impact of different features on user satisfaction. This enables the QFD model to precisely focus on specific and critical user needs during subsequent research and development, avoiding blind spots in product design.

Building on market research, the QFD model further utilizes tools such as the “Affinity Diagram” and “Relationship Diagram” to accurately identify deep user needs, effectively segmenting different user groups and uncovering their unique expectations for smart anti-snoring sleep pillows [4]. Through tools like the “Matrix Diagram”, the QFD model helps companies reasonably measure the relationships between various metrics, achieving a systematic analysis of product characteristics, and providing a more scientific and concrete direction for later product design.

In the context of the broad and complex sleep product market, the integration of the QFD-KANO model addresses the shortcomings of each individual model in problem-solving [5]. While the KANO model emphasizes uncovering latent user expectations, the QFD model organically incorporates these expectations into product design through scientific data analysis methods, enabling more precise fulfillment of the personalized needs of different user groups, thus achieving a high degree of alignment between the product and the market.

2.4. Investigation Sample

Through an offline questionnaire survey, we conducted a study on snoring consumers’ sleep conditions and their willingness to purchase smart anti-snoring sleep pillows, collecting a total of 253 valid questionnaires. The analysis of the survey results was based on the KANO model, with the respondents mainly aged between 20 and 70 years. These participants exhibited a high level of acceptance for new products, and the majority reported that their sleep quality was significantly impacted by pressures related to learning, life, and work.

2.5. Questionnaire

To better analyze users’ needs for the smart anti-snoring sleep pillow, the following fourteen demand points were identified: anti-snoring, anti-electric leakage, head massage, comprehensive snoring recognition, breathable and sweat-absorbing materials, deep silence, cervical massage, App connectivity, heart rate monitoring, early sleep planning, sleep monitoring, smart awakening, sleep assistance, and sleep reports.

The questionnaire employed a bidirectional approach (*i.e.*, addressing both positive and negative aspects) in its questioning. According to the KANO model, users’ preferences for these functions were categorized into five levels: “very necessary”, “expected”, “indifferent”, “acceptable”, and “unacceptable”. This framework allows for an analysis of the degree of demand for the anti-snoring function from customers.

2.6. User Requirements Analysis

The KANO model is widely used to assess the degree of user needs. This model determines issues related to a product or service from two different perspectives: positive and negative, and analyzes users’ psychological states when specific needs are met or unmet. Based on the level of user needs, the analysis results categorize the needs attributes into six types: Essential Needs (M), Desired Needs (O), Charm Needs (A), Undifferentiated Needs (I), Reverse Needs (R), and Questionable Needs (Q). Questionable needs usually arise when respondents do not understand the questionnaire or when there are errors in the questionnaire, and thus, they typically do not occur (See Table 1).

Table 1. KANO model demand statistics table.

Requirement	Essential Needs (M)	Desired Needs (O)	Charm Needs (A)	Undifferentiated Needs (I)	Reverse Needs (R)
Stop snoring	192	38	23	0	0
Anti-creeping	154	49	33	17	0
Head Massage	42	159	33	19	0
Comprehensive snore recognition	43	51	157	2	0
Breathable and Absorbent	139	55	31	28	0
Deep Silence	21	48	112	72	0
Neck Massage	66	103	72	12	0
Connecting App	12	33	52	144	12
Heart Rate Monitoring	17	53	41	142	0
Early to Bed Plan	26	32	71	124	0
Sleep Monitor	111	59	60	23	0
Intelligent Wake-up	64	113	31	40	5
Sleep Aid	48	111	70	21	3
Sleep Report	12	52	139	44	6

To better understand and analyze user needs, the "Better-Worse Coefficient" was employed to analyze the questionnaire results. The "Better-Worse Coefficient", proposed by researchers such as Berger, quantifies the level of user needs into a standardized value using a quantitative statistical method, aiding in a better understanding of and meeting user expectations [6]. The calculation method of the "Better-Worse Coefficient" more clearly reflects the impact on user satisfaction when a particular need is fully met or inadequately met.

In the "Better-Worse Coefficient," the better coefficient represents the level of user satisfaction when a specific need is fully satisfied, while the Worse coefficient signifies the level of user dissatisfaction when a specific need is not adequately met. By calculating the "Better-Worse Coefficient", one can gain insights into the specific effects of various demand factors on user satisfaction and dissatisfaction, thus facilitating better alignment with user needs in the design and development of products and services. The coefficient is calculated based on the following formulas: Better = (O + A)/(M + O + A + I); Worse = (O + M)/(M + O + A + I) × −1.

In this context, O, A, M, and I are four factors representing different demand states: Essential Needs (M), Desired Needs (O), Charm Needs (A), Undifferentiated Needs (I). In the calculation of the "Better-Worse Coefficient", the numerator represents the sum of the number of needs that are fully satisfied and partially satisfied, while the denominator represents the total number of all demand states, including the quantities of must-be needs, expected needs, attractive needs, and indifferent needs [7].

The closer the "Better-Worse Coefficient" is to 1, the higher the degree to which the product or service meets user needs, and the higher the user satisfaction. Conversely, a lower value indicates a higher level of user dissatisfaction. By calculating the "Better-Worse Coefficient", accurate insights into user needs can be derived (See Table 2).

Table 2. The KANO model requirement definition diagram.

Better Value	Worse Value (absolute value)	Degree of Demand
>0.5	>0.5	Desired Needs (O)
<0.5	<0.5	Undifferentiated Needs (I)
>0.5	<0.5	Charm Needs (A)
<0.5	>0.5	Essential Needs (M)

Table 3. "Better-Worse Coefficient" statistics table.

Requirement	Better Value	Worse Value (absolute value)	Final Attributes
Stop snoring	0.24	0.91	Essential Needs
Anti-creeping	0.32	0.8	Essential Needs
Head Massage	0.76	0.79	Desired Needs
Comprehensive snore recognition	0.82	0.37	Charm Needs
Breathable and Absorbent	0.34	0.77	Essential Needs
Deep Silence	0.63	0.27	Charm Needs
Neck Massage	0.69	0.67	Desired Needs
Connecting App	0.35	0.19	Undifferentiated Needs
Heart Rate Monitoring	0.37	0.28	Undifferentiated Needs
Early to Bed Plan	0.41	0.23	Undifferentiated Needs
Sleep Monitor	0.47	0.67	Essential Needs
Intelligent Wake-up	0.58	0.71	Desired Needs
Sleep Aid	0.72	0.64	Desired Needs
Sleep Report	0.77	0.26	Charm Needs

According to the KANO model demand definition chart, and in conjunction with the "Better-Worse coefficient", we analyzed and calculated the functional demand statistics collected from respondents in the survey regarding the smart anti-snoring sleep pillow. The final demand attributes for each function based on the KANO model are presented in **Table 3**.

Based on the "Better-Worse coefficient" sensitivity scatter plot for the smart anti-snoring sleep pillow, the demand points mentioned in the questionnaire report related to the smart anti-snoring sleep pillow are categorized according to the fourteen features: anti-snoring, anti-leakage, head massage, all-direction snoring detection, breathable and sweat-absorbing, deep silence, neck massage, App connectivity, heart rate monitoring, early sleep planning, sleep monitoring, intelligent awakening, sleep assistance, and sleep reports.

According to the importance ranking of demand attributes obtained from the KANO model theory, the above attributes can be arranged as follows: Must-be Needs (M) > Expected Needs (O) > Attractive Needs (A) > Indifferent Needs (I). At the same time, after clarifying the specific distribution of each demand point based on the "Better-Worse coefficient" sensitivity rectangle scatter plot, a secondary importance ranking can be conducted for the same attributes. The priority ranking for must-be needs is as follows: anti-snoring > anti-leakage > breathable and sweat-absorbing > sleep monitoring. Therefore, for must-be needs, the product should focus on the stability and reliability of its functions, enhance quality control efforts, and ensure that the anti-snoring, anti-leakage, breathable and sweat-absorbing, and sleep monitoring functions are of high quality, thus adequately meeting customers' basic needs. The priority ranking for expected needs is as follows: head massage > sleep assistance > neck massage > intelligent awakening. Therefore, with regard to expected needs, emphasis should be placed on user experience, focusing research and development efforts on head massage, neck massage, intelligent awakening, and sleep assistance to ensure the product's comfort and convenience, thereby enhancing user satisfaction and loyalty. For attractive needs, the priority ranking of demand points is as follows: all-direction snoring detection > sleep reports > deep silence. Thus, for attractive needs, innovation should be strengthened, focusing on product development and continuous updates, upgrades, and optimizations to create differentiated and competitive products, thereby increasing the brand's visibility and influence. The priority ranking for indifferent needs is as follows: early sleep planning > heart rate monitoring > App connectivity. Therefore, for indifferent needs, the smart anti-snoring sleep pillow should strengthen support for App connectivity, heart rate monitoring, and early sleep planning, but should not overemphasize these aspects. It is sufficient to ensure the completeness of the product's functions and avoid excessive investment in these areas at the expense of other needs. It is also important to note that 4.74% of respondents expressed concerns about privacy breaches after connecting to the App, so attention should be paid to protecting customers' personal privacy in the App design. Following the initial categorization of user demand results based on the KANO model, further modifications and adjustments should be made in conjunction with the QFD model.

First, we introduce the concept of the "house of quality" from the QFD model to systematically establish the relationship between user needs and design characteristics. The outputs of the house of quality are presented, with the ranking of weight values reflecting the degree of closeness between design characteristics and user needs.

Table 4. Mapping between product requirements and design.

Design Features	Weight Value
Stop snoring	Q1
Anti-creep	Q2
Head Massage	Q3
Comprehensive snore recognition	Q4
Breathable and Absorbent	Q5
Deep Silence	Q6
Neck Massage	Q7
Connecting App	Q8
Heart Rate Monitoring	Q9
Early to Bed Plan	Q10
Sleep Monitor	Q11
Intelligent Wake-up	Q12
Sleep Aid	Q13
Sleep Report	Q14

Through the house of quality, it can be observed that design characteristics such as Q1, Q2, and Q3 have a high correlation with the needs of elderly users (See Table 4). Therefore, during the design process of the smart anti-snoring sleep pillow, special emphasis should be placed on the realization of these design characteristics. Meanwhile, design characteristics with lower weight values, such as Q8, Q9, and Q10, should also be considered. These characteristics have a lower correlation with the overall needs of elderly users, so they can be placed in a relatively secondary position in product design, ensuring that their secondary nature does not compromise the optimization of primary design characteristics.

3. Design Practice of the Smart Anti-Snoring Sleep Pillow

3.1. Product Structure Design

The smart anti-snoring sleep pillow in this project consists of two parts: the pillow and the side device. The pillow hardware includes an airbag, solenoid valve, main control unit, sound sensor, wireless communication module, and pressure sensor;

the side device hardware includes the inflation and deflation components, main control unit, data analysis module, power supply, and Bluetooth (See **Figure 1**).

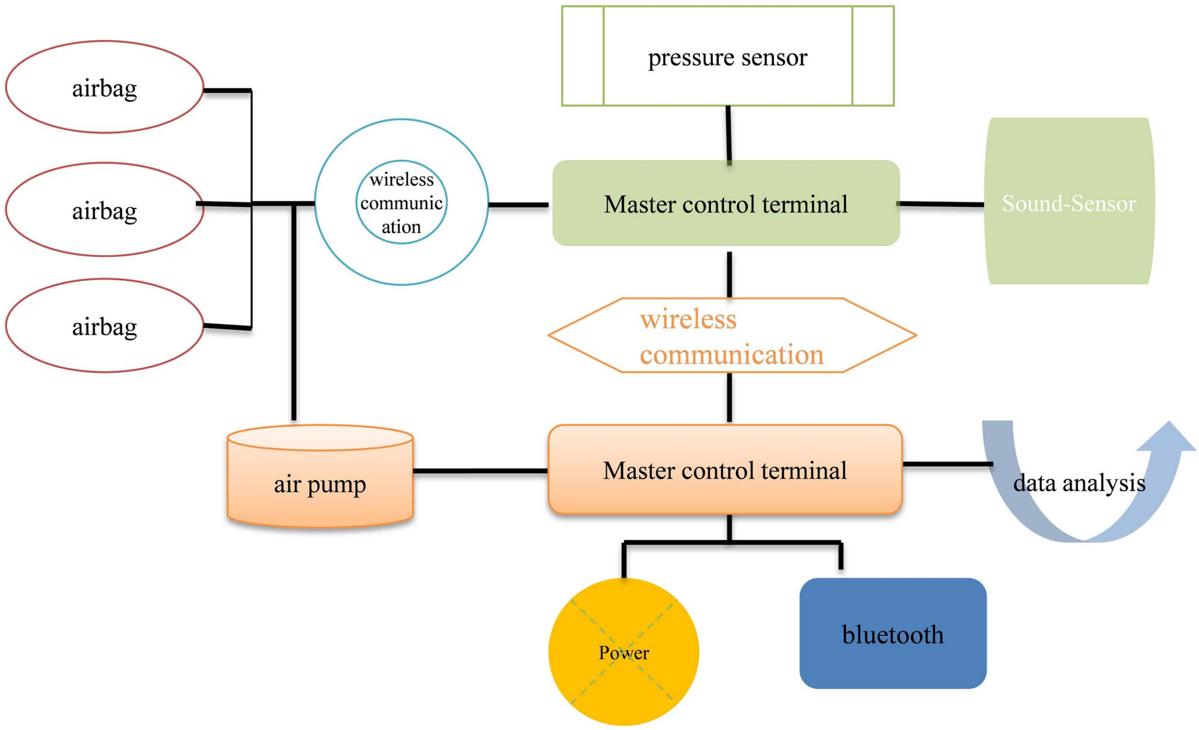

Figure 1. Hardware system structure diagram.

3.2. Product Operation Flow Chart

The smart anti-snoring sleep pillow in this project utilizes snoring recognition monitoring and processing technology, as well as a sound sensor, to drive an air pump that inflates and deflates the airbag inside the pillow. This adjustment changes the user's head position, effectively reducing or eliminating snoring sounds (See **Figure 2**).

3.3. Product System Software Technology

The software technology component of this project mainly includes several parts: data communication, data analysis and working commands, pressure sensors, sound sensors, and driving pumps. The main control unit connects multiple important components and serves as the core of the entire project, enabling intelligent operations. By connecting to a mobile app, it can record sleep patterns in real time. The pressure sensor in the pillow's airbag can determine the position of the head, controlling the inflation of the airbag to adjust the user's head position and sleeping posture, ultimately achieving the goal of reducing or eliminating snoring sounds. The sound sensor collects snoring signals and transmits them to the mobile app via Bluetooth. The micro pump is controlled by a transistor, determining whether the pump operates based on commands from the main control unit.

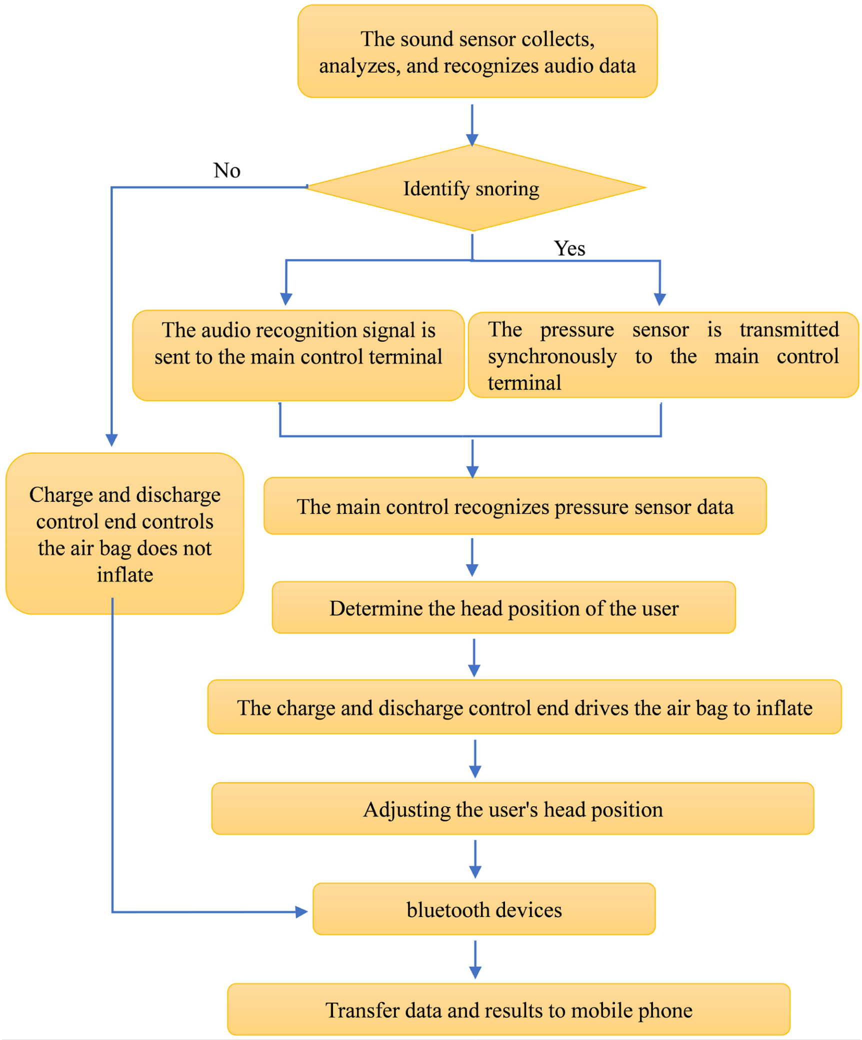

Figure 2. Product operation flow chart.

3.3.1. Detection and Recognition of Snoring Signals

The detection and recognition of snoring signals refer to the process of using a sound sensor to detect all sounds, while the intelligent system distinguishes between snoring and non-snoring signals based on algorithms, providing foundational support for subsequent operations. The snoring signal recognition for the smart anti-snoring sleep pillow is divided into three steps: first, effective noise reduction is applied to the sound signals; then, the denoised sound signals are sent to the side device, where unique calculations analyze the frequency spectrum range to identify snoring sounds; finally, the snoring signals are classified and transmitted to a self-developed mobile app. The recognition of snoring signals is carried out by the data analysis component, which employs relevant algorithms to achieve high-precision snoring signal recognition. In multiple experiments, the accuracy of snoring recognition reached as high as 94%.

3.3.2. Analysis and Processing of Snoring Signals

Snoring is an abnormal sound produced during sleep due to the narrowing of the upper airway, characterized by irregular audio patterns and classified as noise. The analysis and processing of snoring signals consist of two aspects: the detection and recognition of snoring signals, as well as the theoretical analysis of these signals. Detection and recognition primarily focus on identifying snoring signals from various audio signals, providing foundational support for further processing; theoretical analysis involves a detailed examination of the characteristics of snoring signals to assess the likelihood of the user having a condition, thereby supporting medical diagnosis. Therefore, this project can accurately identify audio signals and analyze snoring signals, aiding users in recognizing and improving their snoring issues.

3.3.3. Noise Reduction of Snoring Signals

Traditional spectral subtraction and Wiener filtering methods are employed for the preprocessing of sleep snoring signals. First, traditional spectral subtraction is used for initial enhancement of the signals; then, the subspace projection method projects the signals into two subspaces: noise and clean signals, and calculates the signal-to-noise ratio (SNR); finally, the transfer function of the Wiener filter is derived using the SNR. After processing with spectral subtraction and Wiener filtering, the snoring signals will be cleaner and have reduced noise interference.

3.3.4. Snore Recognition Data Monitoring

Table 5. Snore recognition test data.

Snore sample	Number of actual snore segments	Monitor the number of snoring segments
Sample 1	45	43
Sample 2	53	52
Sample 3	50	47
Sample 4	46	46
Sample 5	42	40
Sample 6	55	54
Sample 7	51	49
Sample 8	49	48
Sample 9	54	54
Sample 10	57	55

Assemble the pillow of the smart anti-snoring sleep pillow with the side device, then download the App on the mobile phone and connect it to the smart anti-snoring sleep pillow via Bluetooth. You will need to log in to the App's main interface to check if the connection is successful and to set the corresponding functions. After successful setup, play the prepared snoring samples to conduct a snoring recognition test on the smart anti-snoring sleep pillow. Collect and organize the snoring data recognized by the App on the mobile phone, and compare it with the actual played snoring data for error analysis. The experimental data is as follows (See Table 5).

3.3.5. Detection Result Analysis

The accuracy of snoring signal recognition determines the operational choices made by the smart anti-snoring sleep pillow after identifying snoring sounds, playing a crucial role in the overall functionality of the product. This aspect is also highly significant for the sleep experience of the product users. The data results in Table 5 indicate that the smart anti-snoring sleep pillow can achieve an accuracy rate of up to 94% when operating, with only a slight discrepancy from the actual number of snoring segments, demonstrating a relatively accurate snoring recognition rate.

4. Conclusion

Currently, health issues related to insomnia and snoring are on the rise, severely affecting people's physical and mental well-being. In response to this situation, this study conducted a questionnaire survey targeting individuals troubled by insomnia and snoring, and performed an in-depth analysis using the KANO model. This clarified consumers' demand points for the smart anti-snoring sleep pillow and prioritized these needs, leading to the design practice of the smart anti-snoring sleep pillow. The results show that the snoring recognition accuracy of this project's smart anti-snoring sleep pillow reaches 94%, with only a small difference between the actual number of snoring segments and the predicted snoring segments, indicating a high level of snoring recognition accuracy. The snoring recognition technology in the smart anti-snoring sleep pillow exhibits high reliability and accuracy, which will provide users with a superior sleep experience.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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