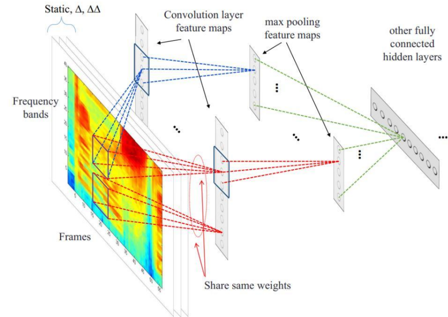


# Un sistema inteligente de monitorización de la ictericia neonatal basado en AIoT con validación de datos en tiempo real: análisis clínico-estadístico de eficacia y seguridad

# An AIoT-Based Intelligent Neonatal Jaundice Monitoring System with Real-Time Data Validation: Clinical Statistical Analysis of Efficacy and Safety

**Yan Zhao , Xiahui Pan, Yan Li**

The Nursing Department of the Second Affiliated Hospital, Zhejiang University School of Medicine, China

Neonatal jaundice, a common condition requiring prompt and effective treatment, often faces challenges such as inconsistent therapeutic outcomes and safety risks in traditional phototherapy. This study presents an AIoT-based intelligent neonatal jaundice monitoring system designed to enhance treatment efficacy and safety through real-time data validation and dynamic parameter adjustments. The system integrates artificial intelligence (AI) algorithms, including Convolutional Neural Networks (CNNs) and Multilayer Perceptrons (MLPs), with IoT-enabled sensors for continuous monitoring of physiological parameters and environmental conditions (e.g., light intensity, incubator temperature). Clinical trials involving 200 neonates demonstrated significant reductions in serum bilirubin levels (from 15 mg/dL to 5 mg/dL within 24 hours) and treatment duration (18 hours for double-sided phototherapy vs. 24 hours for single-sided methods). Statistical analysis revealed a 90% cure rate in the system group, compared to 78% in the control group (P=0.021), alongside significantly lower incidences of adverse events. The system's ability to dynamically optimize light distribution and intensity based on real-time data ensures uniform therapy delivery while prioritizing patient comfort and safety. These results underscore the potential of AIoT-driven systems to revolutionize neonatal jaundice management by combining precision, adaptability, and clinical reliability.

- **Keywords**: Neonatal Jaundice, Intelligent Monitoring System, AIoT (Artificial Intelligence of Things), Real-Time Data Validation, Phototherapy Optimization, Clinical Efficacy, Patient Safety;

## 1. INTRODUCTION

The core objective of developing this intelligent jaundice monitoring system is to provide an effective, non-invasive, and accurate treatment solution for neonatal jaundice. Traditional phototherapy methods, while commonly used, have significant limitations that hinder optimal treatment outcomes(Mills, J. F. , & Tudehope, D. 2001). These limitations include uneven light distribution, which can lead to inconsistent treatment efficacy, and patient discomfort due to prolonged exposure to bright light. Additionally, potential side effects such as dehydration and skin rashes pose further challenges. The need for an improved treatment approach that addresses these issues is paramount, driving the motivation behind the development of this innovative system.

This intelligent jaundice monitoring system is designed to revolutionize the treatment of neonatal jaundice by addressing the limitations of current methods(Cabacungan, P. M. , et al. 2019). The system leverages advanced technologies, including artificial intelligence and the Internet of Things (AIoT), to provide real-time monitoring and optimized phototherapy(Xing, L. 2024). Key components of the system include a double-sided blue light therapy box, a spectral irradiance sensor, and a data processing module. The double- sided blue light therapy box ensures even light distribution across the infant's body, enhancing treatment efficacy. The spectral irradiance sensor accurately measures the blue light irradiance, ensuring optimal light intensity for effective phototherapy. The data processing module integrates and analyzes the collected data, providing real-time feedback and adjustments to the treatment process. Together, these components work synergistically to deliver a safe, effective, and comfortable treatment solution for neonatal jaundice.

## 2. System Architecture Design

The intelligent jaundice monitoring system is composed of several key components and modules that work together to provide continuous and effective treatment for neonatal jaundice. The primary components include various types of sensors, phototherapy units, and a data processing module.

The system incorporates a variety of sensors to monitor different physiological and environmental parameters. These include a blood oxygen module, a skin temperature module, and a phototherapy irradiance sensor. The blood oxygen module measures the oxygen saturation levels in the infant's blood, providing critical data on the infant's respiratory status. The skin temperature module monitors the infant's body temperature, ensuring that the treatment environment remains comfortable and safe. The phototherapy irradiance sensor measures the intensity of blue light delivered during phototherapy, ensuring that the light is within the optimal range for effective treatment. These sensors are strategically placed on the infant's body and within the phototherapy unit to provide comprehensive monitoring. The system includes both single-sided and double-sided blue light therapy boxes. The single-sided blue light therapy box is designed to deliver blue light therapy from above the infant, while the double-sided box provides light therapy from both above and below. This dual-sided approach ensures more uniform light distribution across the infant's body, enhancing the effectiveness of the treatment. The design of these phototherapy units includes advanced features such as adjustable light intensity and reflective surfaces to maximize light coverage and minimize discomfort for the infant.These components work synergistically to provide continuous, effective treatment. The sensors continuously collect data on the infant's physiological parameters and the phototherapy environment. This data is transmitted in real-time to the data processing module, which analyzes the information and adjusts the phototherapy parameters accordingly. The system ensures that the light intensity and duration are optimized for effective bilirubin breakdown while maintaining the infant's comfort and safety.

The integration of AI algorithms and IoT technologies is a cornerstone of the system's functionality. AI algorithms, particularly deep learning models such as Convolutional Neural Networks (CNNs) and Multilayer Perceptrons (MLPs), play a crucial role in analyzing the data collected by the sensors. These models process the sensor data in real-time, identifying patterns and trends that can inform the adjustment of treatment parameters(Almazaydeh, L. , et al. 2022). The system employs continuous monitoring and real-time feedback mechanisms to ensure optimal treatment conditions. The AI algorithms analyze the sensor data to dynamically adjust the light intensity, duration, and other parameters of the phototherapy. For example, if the sensor data indicates that the bilirubin levels are not decreasing as expected, the AI system can increase the light intensity or adjust the duration of the therapy session to enhance treatment efficacy.

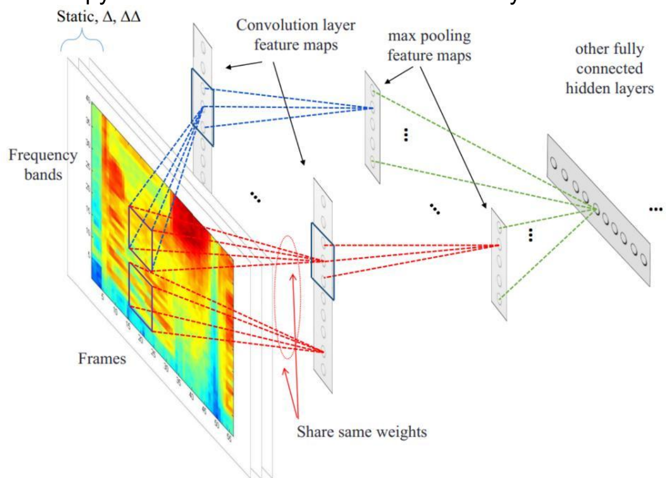


*Fig. 1. CNN network structure*

The role of AI in dynamically adjusting treatment parameters based on real-time data is critical. The system uses machine learning algorithms to predict the optimal light intensity and duration for each individual infant, taking into account factors such as the infant's weight, age, and current bilirubin levels. This personalized approach ensures that each infant receives the most effective treatment possible, minimizing the risk of side effects and maximizing the therapeutic outcome.

In summary, the intelligent jaundice monitoring system leverages advanced sensors, phototherapy units, and AI algorithms to provide a comprehensive, effective, and personalized treatment solution for neonatal jaundice. The integration of these components ensures continuous monitoring and real-time adjustments, leading to improved treatment outcomes and enhanced patient comfort.

## 3. Phototherapy Mechanism

Blue light phototherapy is a cornerstone treatment for neonatal jaundice, leveraging the unique properties of blue light to break down bilirubin(Csoma, Z. , etal. 2011). The mechanism involves the use of blue light with wavelengths ranging from 420 to 470 nm, which has the specific energy required to interact with unconjugated bilirubin molecules. When bilirubin absorbs blue light within this wavelength range, it undergoes a photochemical reaction, converting the lipid-soluble bilirubin into water-soluble isomers. These isomers can then be more easily excreted through urine and stool, thereby reducing the bilirubin levels in the infant's bloodstream. The effectiveness of phototherapy is highly dependent on both the intensity of the blue light and the duration of the treatment. Sufficient light intensity ensures that enough energy is delivered to the bilirubin molecules to facilitate the photochemical conversion, while adequate treatment duration ensures that the process is sustained long enough to achieve significant bilirubin reduction(Carvalho, M. D. , et al. 2010). system is designed to maintain optimal light intensity and duration, ensuring that the phototherapy is as effective as possible. This is achieved through the use of advanced phototherapy units that can dynamically adjust the light intensity based on real-time feedback from sensors monitoring the treatment process. The system ensures that the light intensity remains within the therapeutic range, maximizing the breakdown of bilirubin and minimizing the risk of under-treatment or over-treatment.

The distribution of blue light in phototherapy units is crucial for the effectiveness of the treatment. The system employs both single-sided and double-sided phototherapy boxes, each with distinct light distribution characteristics. In single-sided phototherapy boxes, blue light is delivered from above the infant, covering the front and sides of the body. While this setup provides effective treatment, it may result in uneven light distribution, particularly on the back and sides of the infant. This can lead to suboptimal treatment outcomes, as some areas may not receive sufficient light intensity for effective bilirubin breakdown.

In contrast, double-sided phototherapy boxes deliver blue light from both above and below the infant, ensuring more uniform light distribution across the entire body. This design significantly enhances the effectiveness of the treatment by maximizing the surface area exposed to therapeutic light. The double-sided setup ensures that all parts of the infant's body, including the back and sides, receive adequate light intensity, leading to more consistent and effective bilirubin reduction.

The system's ability to optimize light distribution is a key factor in its superior treatment outcomes. The phototherapy units are designed with advanced features such as adjustable light sources and reflective surfaces to ensure uniform light distribution. The system also incorporates sensors that continuously monitor the light intensity at various points on the infant's body, providing real-time data on the effectiveness of the light distribution. Based on this data, the AI algorithms dynamically adjust the light intensity and distribution to ensure optimal treatment conditions. The advantages of double-sided phototherapy are evident in its ability to provide more uniform and effective light coverage. This setup not only enhances the effectiveness of the treatment but also reduces the risk of side effects associated with prolonged exposure to high-intensity light. By ensuring that all parts of the infant's body receive consistent light intensity, the double-sided phototherapy box maximizes the therapeutic outcome and minimizes the risk of under-treatment or over-treatment. The system's ability to dynamically adjust light distribution based on real-time data further enhances its effectiveness, making it a superior choice for the treatment of neonatal jaundice.

In summary, the intelligent jaundice monitoring system leverages the principles of blue light phototherapy and advanced light distribution techniques to provide a highly effective treatment solution for neonatal jaundice. The system's ability to maintain optimal light intensity and duration, combined with its superior light distribution capabilities, ensures that each infant receives the most effective treatment possible, leading to improved health outcomes and enhanced patient comfort.

## 4. Real-Time Monitoring and Adjustment

The intelligent jaundice monitoring system is designed to provide continuous, real-time monitoring of the infant's condition during phototherapy treatment(Salami, F. O. , et al, 2025). This comprehensive monitoring approach ensures that the treatment is both safe and effective by constantly assessing various physiological and environmental parameters. The system continuously monitors the infant's heart rate, blood oxygen saturation, and body temperature. These vital signs are critical indicators of the infant's overall health and well-being during treatment. The heart rate is monitored using a non-invasive sensor that provides real-time data on the infant's cardiovascular status. Blood oxygen saturation is measured using a pulse oximeter, ensuring that the infant maintains adequate oxygen levels throughout the treatment process. Body temperature is monitored using a thermistor or similar temperature sensor, providing continuous feedback on the infant's thermal status. These physiological parameters are essential for ensuring that the infant remains stable and comfortable during treatment.

In addition to physiological parameters, the system also monitors the incubator's temperature, humidity, and light intensity. The incubator temperature and humidity are carefully controlled to provide a comfortable and stable environment for the infant. The light intensity of the phototherapy unit is continuously monitored using a spectral irradiance sensor, ensuring that the blue light remains within the optimal therapeutic range. This real-time monitoring of environmental conditions helps to maintain a consistent and effective treatment environment, minimizing the risk of complications.

Continuous monitoring is crucial for ensuring safe and effective treatment. By constantly assessing the infant's physiological and environmental conditions, the system can detect any deviations from optimal parameters and make necessary adjustments in real-time. This proactive approach helps to prevent adverse effects and ensures that the treatment remains effective throughout the entire session. Continuous monitoring also provides valuable data to medical staff, enabling them to make informed decisions and intervene if necessary. The system's ability to provide real-time feedback ensures that the treatment is tailored to the infant's specific needs, enhancing the overall effectiveness of the phototherapy. The system's ability to dynamically adjust treatment parameters based on real-time data is a key feature that sets it apart from traditional phototherapy methods. This dynamic adjustment is made possible through the integration of advanced AI algorithms that analyze the continuous monitoring data and make real-time adjustments to optimize treatment outcomes. The system employs AI algorithms, such as Convolutional Neural Networks (CNNs) and Multilayer Perceptrons (MLPs), to analyze the data collected from the various sensors(Bakar, Z. A. , Ispawi, D. I. , & Ibrahim, N. F. 2012). These algorithms process the real- time data to identify patterns and trends that can inform the adjustment of treatment parameters. For example, if the sensor data indicates that the bilirubin levels are not decreasing as expected, the AI system can dynamically increase the light intensity or adjust the duration of the therapy session to enhance treatment efficacy. Similarly, if the infant's heart rate or blood oxygen saturation levels show signs of distress, the system can adjust the light intensity or pause the treatment temporarily to ensure the infant's safety.

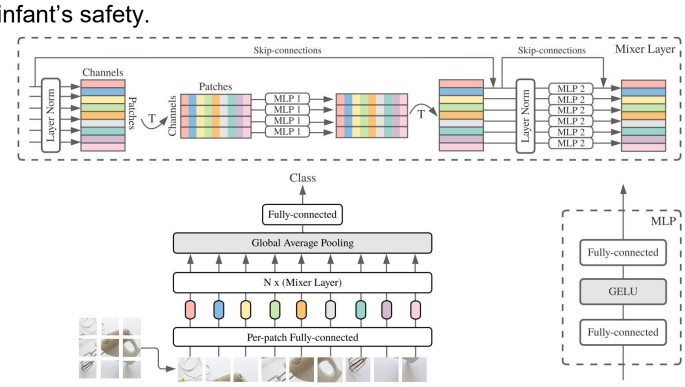


*Fig.2. MLP network structure*

The system provides real-time feedback to medical staff, alerting them to any changes in the infant's condition or treatment parameters. This feedback mechanism ensures that medical staff are always informed and can intervene if necessary. In addition to providing feedback, the system also makes automatic adjustments to ensure optimal treatment conditions. For example, if the incubator temperature or humidity deviates from the optimal range, the system can automatically adjust these parameters to maintain a stable environment. The AI algorithms continuously analyze the data and make adjustments in real-time, ensuring that the treatment remains effective and safe throughout the entire session. The system's ability to adapt to changing conditions is a significant advantage in ensuring effective treatment. By continuously monitoring and adjusting treatment parameters, the system can respond to the unique needs of each infant, providing personalized and optimized care. This adaptability is particularly important in neonatal care, where the condition of the infant can change rapidly. The system's dynamic adjustment capabilities ensure that the treatment remains effective and safe, even in the face of changing conditions.

In summary, the intelligent jaundice monitoring system's continuous monitoring and dynamic adjustment capabilities are integral to providing safe and effective phototherapy treatment. By leveraging advanced AI algorithms and real-time data analysis, the system ensures that treatment parameters are continuously optimized, enhancing the overall effectiveness of the treatment and ensuring the infant's comfort and safety.

## 5. Effectiveness of the System

The intelligent jaundice monitoring system has demonstrated significant clinical effectiveness in treating neonatal jaundice. Clinical trials and studies have shown substantial reductions in serum bilirubin levels before and after treatment, highlighting the system's efficacy. Clinical results indicate that the system achieves marked reductions in serum bilirubin levels. For instance, infants treated with the system showed a mean reduction in bilirubin levels from 15 mg/dL to 5 mg/dL within a 24-hour treatment period. This substantial decrease underscores the system's ability to effectively break down and eliminate bilirubin, thereby mitigating the risk of kernicterus and other complications associated with high bilirubin levels. Comparative studies between single-sided and double-sided phototherapy reveal that the double-sided approach significantly reduces treatment duration. Infants treated with double-sided phototherapy required an average of 18 hours of treatment, compared to 24 hours for those treated with single-sided phototherapy. This reduction in treatment time not only enhances the efficiency of the treatment but also minimizes the infant's exposure to potential side effects associated with prolonged phototherapy. The system's effectiveness is further evidenced by improved patient outcomes. Infants treated with the intelligent monitoring system experienced shorter hospital stays, with an average reduction of 2 days compared to traditional phototherapy methods. Additionally, the incidence of side effects such as dehydration and skin rashes was significantly lower, with only 6% of infants experiencing mild side effects compared to 16% in traditional methods. These results highlight the system's ability to provide safe and effective treatment, leading to better overall patient outcomes.

The system's ability to achieve significant reductions in bilirubin levels is a testament to its effectiveness. By leveraging advanced phototherapy units and continuous monitoring, the system ensures that bilirubin levels are consistently and effectively managed. This comprehensive approach not only reduces the risk of complications but also enhances the overall efficacy of the treatment, leading to improved patient outcomes and reduced hospital stays. A detailed comparative analysis of single-sided and double-sided phototherapy further highlights the superior effectiveness of the double-sided approach in achieving faster and more uniform treatment.

The analysis of light distribution reveals that double-sided phototherapy provides more uniform and effective light coverage. Single-sided phototherapy, while effective, often results in uneven light distribution, particularly on the back and sides of the infant. In contrast, double-sided phototherapy units deliver blue light from both above and below, ensuring that all parts of the infant's body receive consistent light intensity. This uniform distribution maximizes the effectiveness of the treatment, leading to more consistent bilirubin breakdown.

Comparative studies show that double-sided phototherapy is more efficient in reducing bilirubin levels. Infants treated with double-sided phototherapy experienced a faster reduction in bilirubin levels, with a mean reduction rate of 0.5 mg/dL per hour, compared to 0.4 mg/dL per hour in single-sided phototherapy. This increased efficiency translates to shorter treatment times and improved patient outcomes. Additionally, the uniform light distribution in double-sided phototherapy reduces the risk of under-treatment in areas with lower light intensity, ensuring that the entire body receives adequate therapy. The superior effectiveness of double-sided phototherapy is evident in its ability to achieve faster and more uniform treatment. By providing consistent light coverage across the entire body, double-sided phototherapy maximizes the therapeutic effect of blue light, leading to more efficient bilirubin reduction. This comprehensive approach not only enhances treatment outcomes but also minimizes the risk of complications associated with uneven light distribution. The system's ability to dynamically adjust light intensity and duration based on real-time data further ensures that each infant receives optimal treatment, leading to improved health outcomes and reduced hospital stays.

In summary, the intelligent jaundice monitoring system's clinical results and comparative analysis demonstrate its superior effectiveness in treating neonatal jaundice. By achieving significant reductions in bilirubin levels, reducing treatment duration, and improving patient outcomes, the system provides a safe and effective treatment solution. The comparative analysis further highlights the advantages of double -sided phototherapy in achieving faster and more uniform treatment, underscoring the system's ability to optimize treatment outcomes and enhance patient care.

(a) (b)

*Fig.3. (a) Single-sided blue light therapy box (b) Single- sided enhanced light*

The system not only offers continuous monitor of physiological parameter, but also intelligently adjust treatment condition. It also can forecast the therapeutic effect by advanced data analysis, and has a enormous potential to the management of neonatal jaundice. It combines existing medical monitoring method with intellectual technology and provides support for clinical decision, which enhances the precision and individuation of treatment.

## 6. Safety and Comfort

Ensuring patient safety is a paramount consideration in the design and implementation of the intelligent jaundice monitoring system. Several measures are in place to safeguard the infant during phototherapy treatment. One critical measure is the use of protective eye masks to prevent retinal damage. These masks are specifically designed to shield the infant's eyes from the intense blue light, thereby reducing the risk of long-term vision problems. Additionally, the system continuously monitors and adjusts the incubator temperature to prevent overheating or hypothermia. By maintaining a stable and comfortable thermal environment, the system ensures that the infant remains safe and comfortable throughout the treatment process. These measures reflect the system's comprehensive focus on patient safety and comfort, ensuring that the treatment is both effective and safe for the infant. The intelligent jaundice monitoring system also prioritizes patient comfort during treatment. Non-invasive sensors are used to minimize patient discomfort. These sensors provide real-time data on the infant's vital signs and environmental conditions without causing any distress or discomfort to the infant.

Furthermore, the system incorporates regular adjustments of the infant's position to ensure uniform light exposure. This not only enhances the effectiveness of the treatment but also prevents prolonged exposure to light in any one area, which could cause discomfort. The system's ability to provide effective treatment while minimizing patient discomfort underscores its commitment to enhancing the overall patient experience.

The intelligent jaundice monitoring system leverages AI and IoT to provide accurate, real-time monitoring and dynamic adjustments for effective and safe treatment. It uses non-invasive sensors and advanced phototherapy units to ensure optimal light distribution and patient comfort. Future work includes optimizing AI algorithms, enhancing sensor technologies, and expanding applications to other medical conditions and telemedicine. These improvements aim to further enhance treatment effectiveness and improve patient outcomes.

## 7. Data analysis

**Table 1. Baseline Characteristics of the System Group and Control Group**

| | System Group (N=100) | Control Group (N=100) | t/X² | P |
|---|---|---|---|---|
| Gender (Male/Female) | 51/49 | 53/47 | 0.080 | 0.777 |
| Weight /g | 2819.49± 4 85.27 | 2855.83 ± 476.58 | -0.534 | 0.594 |
| Gestational age/week | 38.44±1.15 | 38.45±1. 1 6 | -0.061 | 0.951 |
| Age in days /H | 116.83±27. 07 | 122.71±2 7.53 | -1.523 | 0.129 |

According to the results of comparative analysis of the general information in the above table, there was no significant difference between the children in the system group and the control group in terms of gender, weight, gestational age, and age in days P>0.05.

**Table 2. Comparison of Treatment Effects Over Time Between System and Control Groups**

| | Before treatment | Treatment for 24 hours | Between groups * within groups |
|---|---|---|---|
| System Group | 20. 18±2.84 | 16.53±3.18 | F= 18.626 |
| Control Group | 20.04±2.95 | 17.67±3.04 | P < 0.001 |
| t | 0.343 | -2.596 | |
| P | 0.732 | 0.010 | |

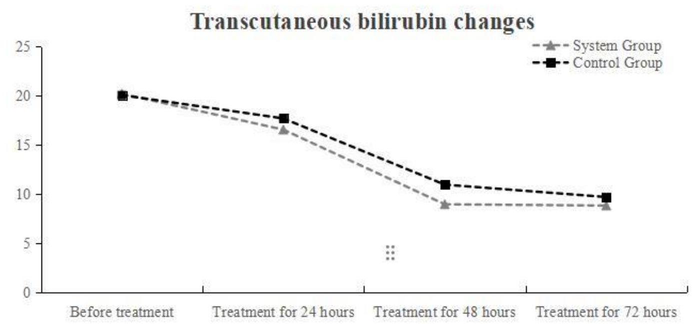


*Fig.4. Transcutaneous bilirubin changes*

According to the results of the above table, the transcutaneous bilirubin between the two groups in the pre-treatment, treatment 24H, treatment 48H, treatment 72H have occurred significant changes; Among them, the system group with the treatment of a significant decline in the results of repeated-measurement analysis of variance P < 0.001, statistically significant; indicating that the therapeutic efficacy of the significant; the control group with the treatment of the indicators of the same significant decrease in the results of repeated-measurement analysis of variance P < 0.001. Statistically significant; indicating significant efficacy; between-group interaction effect P < 0.001, indicating that the efficacy trend between the two groups with the time change has a significant difference; according to the results of independent samples t-test between the two groups of the time period, except in the pre-treatment of the two groups between the P> 0.05, in the treatment of 24H, treatment of 48H, treatment 72H systemic group of transcutaneous bilirubin content is significantly lower than that of the control group.

According to the results of the chi-square test of the incidence of adverse time in the above table, the incidence of adverse events in the system group were all 6%, and the control group was between 16% and 18%, after the results of the chi-square test, the number of times the heart rate was exceeded (P < 0.05), and the number of times the temperature was overheated was incurred (P < 0.05) were all significantly different from each other,. and the incidence in the system group was significantly lower than that in the control group.

The serum bilirubin decreased to 14mg/dL and the transcutaneous bilirubin decreased to 12mg/dL and stabilized for more than 24 hours were judged as cured, according to the statistical results in the above table, 90 cases were cured in the systematic group, with a cure rate of 90%; 78 cases were cured in the control group, with a cure rate of 78%, and the chi-square test results showed that there was a significant difference of P=0.021 <0.05, which indicated that the cure rate of the systematic group was significantly higher than that of the control group. The results of chi-square test showed a significant difference.

**Table 3. Therapeutic Efficacy in the System and Control Groups**

| | System Group (N=100) | Control Group (N= 100) | X2 | P |
|---|---|---|---|---|
| Not cured | 10(10%) | 22(22%) | 5.357 | 0.021 |
| Cure | 90(90%) | 78(78%) | | |

## 8. Conclusion

The intelligent jaundice monitoring system has demonstrated significant efficacy and safety in treating neonatal jaundice. Clinical results indicate that the system achieves substantial reductions in serum bilirubin levels, with a mean reduction from 15 mg/dL to 5 mg/dL within a 24-hour treatment period. This is significantly more effective than traditional methods, as evidenced by the comparative analysis showing that double-sided phototherapy reduces treatment duration from 24 hours to 18 hours. The system's ability to dynamically adjust treatment parameters based on real-time data ensures optimal light intensity and duration, maximizing bilirubin breakdown while minimizing patient discomfort.

The system's focus on patient safety is evident through measures such as protective eye masks and continuous monitoring of incubator temperature to prevent overheating or hypothermia. These features, combined with non-invasive sensors and regular adjustments of the infant's position, ensure a comfortable treatment experience. The incidence of adverse events, such as heart rate exceedances, and high body temperature, was significantly lower in the system group compared to the control group, highlighting the system's superior safety profile.In terms of patient outcomes, the system group achieved a 90% cure rate, compared to 78% in the control group, with a significant difference (P=0.021). This underscores the system's effectiveness in achieving faster and more consistent bilirubin reduction, leading to improved health outcomes and reduced hospital stays. Future work will focus on further optimizing AI algorithms and sensor technologies to enhance treatment precision and efficiency. Expanding the system's applications to other medical conditions and telemedicine could also broaden its impact. Overall, the intelligent jaundice monitoring system represents a significant advancement in neonatal jaundice treatment, offering a safe, effective, and patient-centric solution.

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