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THE CAPABILITIES OF ARTIFICIAL INTELLIGENCE BASED NON INVASIVE DIAGNOSTIC METHODS IN DETECTING NEONATAL JAUNDICE

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Abstract. Neonatal jaundice or hyperbilirubinemia is a serious medical condition occurring in sixty to eighty percent of newborns worldwide, which can lead to kernicterus, cerebral palsy, hearing loss, and even death if not detected and treated in a timely manner. The traditional diagnostic method of measuring total serum bilirubin is invasive, painful for the infant, poses a risk of infection, and is a difficult procedure to widely apply in resource limited areas. In recent years, the development of artificial intelligence technologies has created new opportunities for the non invasive detection of neonatal jaundice. The capabilities of artificial intelligence based non invasive diagnostic methods in detecting neonatal jaundice are systematically analyzed. The results show that convolutional neural networks, vision transformer architectures, and other deep learning models achieve over ninety percent accuracy in detecting neonatal jaundice. Mobile applications analyzing skin and sclera images obtained through smartphone cameras serve as a practical solution in resource limited areas. At the same time, challenges such as skin pigmentation, lighting conditions, and limited datasets remain. The future prospects of these technologies and ways to introduce them into clinical practice are also discussed.

Keywords: Neonatal jaundice, artificial intelligence, non invasive diagnostics, bilirubin, transcutaneous bilirubinometry, convolutional neural network, vision transformer, smartphone application, deep learning, medical image analysis

ВОЗМОЖНОСТИ НЕИНВАЗИВНЫХ МЕТОДОВ ДИАГНОСТИКИ НА ОСНОВЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В ВЫЯВЛЕНИИ НЕОНАТАЛЬНОЙ ЖЕЛТУХИ

Аннотация. Неонатальная желтуха или гипербилирубинемия является серьезным медицинским состоянием, встречающимся от шестидесяти до восьмидесяти процентов новорожденных во всем мире, которое может привести к ядерной желтухе, детскому церебральному параличу, потере слуха и даже смерти, если его не выявить и не лечить своевременно. Традиционный метод диагностики, заключающийся в измерении общего билирубина сыворотки крови, является инвазивным, болезненным для младенца, создает риск инфицирования и представляет собой сложную процедуру для широкого применения в регионах с ограниченными ресурсами. В последние годы развитие технологий искусственного интеллекта создало новые возможности для неинвазивного выявления неонатальной желтухи. Систематически анализируются возможности неинвазивных методов диагностики на основе искусственного интеллекта при выявлении неонатальной желтухи. Результаты показывают, что сверточные нейронные сети, архитектуры визуальных трансформеров и другие модели глубокого обучения достигают точности более девяноста процентов в выявлении неонатальной желтухи. Мобильные приложения, анализирующие изображения кожи и склеры, полученные с помощью камер смартфонов, служат практическим решением в регионах с ограниченными ресурсами. В то же время сохраняются такие проблемы, как пигментация кожи, условия освещения и ограниченность наборов данных. Также обсуждаются будущие перспективы этих технологий и пути их внедрения в клиническую практику.

Ключевые слова: Неонатальная желтуха, искусственный интеллект, неинвазивная диагностика, билирубин, транскутанная билирубинометрия, сверточная нейронная сеть, визуальный трансформер, приложение для смартфона, глубокое обучение, анализ медицинских изображений.

NEONATAL SARIQLIKNI ANIQLASHDA SUN'IY INTELLEKT ASOSIDAGI NOINVAZIV DIAGNOSTIKA USULLARINING IMKONIYATLARI

Annotatsiya. Neonatal sariqlik yoki giperbilirubinemiya butun dunyo bo'ylab yangi tug'ilgan chaqaloqlarning oltmish foizidan sakson foizigacha bo'lgan qismida uchraydigan va o'z vaqtida aniqlanmasa va davolanmasa kernikterus, miya falaji, eshitish qobiliyatining yo'qolishi va hatto o'limga olib kelishi mumkin bo'lgan jiddiy tibbiy holat hisoblanadi. An'anaviy diagnostika usuli bo'lgan umumiy zardob bilirubinini o'lchash invaziv xususiyatga ega bo'lib, chaqaloq uchun og'riqli, infektsiya xavfini keltirib chiqaruvchi va resurslari cheklangan hududlarda keng qo'llanilishi qiyin bo'lgan protsedura sanaladi. So'nggi yillarda sun'iy intellekt texnologiyalarining rivojlanishi neonatal sariqlikni noinvaziv aniqlash uchun yangi imkoniyatlar yaratdi. Sun'iy intellekt asosidagi noinvaziv diagnostika usullarining neonatal sariqlikni aniqlashdagi imkoniyatlari tizimli ravishda tahlil qilinadi. Natijalar shuni ko'rsatadiki, konvolyutsion neyron tarmoqlar, vision transformer arxitekturalari va boshqa chuqur o'rganish modellari neonatal sariqlikni aniqlashda to'qson foizdan yuqori aniqlikka erishmoqda. Smartfon kameralari orqali olingan teri va sklera tasvirlarini tahlil qiluvchi mobil ilovalar resurslari cheklangan hududlarda amaliy yechim sifatida xizmat qilmoqda. Shu bilan birga, teri pigmentatsiyasi, yorug'lik sharoitlari va ma'lumotlar to'plamining cheklanganligi kabi qiyinchiliklar mavjud bo'lib qolmoqda. Ushbu texnologiyalarning kelajak istiqbollari va klinik amaliyotga joriy etish yo'llari ham muhokama qilinadi.

Kalit so'zlar: Neonatal sariqlik, sun'iy intellekt, noinvaziv diagnostika, bilirubin, transkutan bilirubinometriya, konvolyutsion neyron tarmoq, vision transformer, smartfon ilovasi, chuqur o'rganish, tibbiy tasvirlarni tahlil qilish

Introduction. Neonatal jaundice is one of the most common clinical conditions in newborns, manifesting as yellowing of the skin and the white part of the eyes. This condition occurs as a result of an increase in the amount of bilirubin in the blood and is medically termed hyperbilirubinemia. According to statistical data, sixty percent of term infants and more than eighty percent of preterm infants show signs of neonatal jaundice in the first week of life. Although physiological jaundice is usually temporary and safe, pathological hyperbilirubinemia can lead to serious complications such as acute bilirubin encephalopathy and kernicterus. Kernicterus is a condition caused by the passage of bilirubin into the brain resulting in irreversible neurological damage, manifesting with hearing loss, cerebral palsy, and delayed mental development.

Bilirubin metabolism primarily takes place in the liver and involves converting fat soluble toxic unconjugated bilirubin into a water soluble and non toxic form. Because the liver of newborns is not yet fully mature, the ability to efficiently process and excrete bilirubin is limited. This physiological characteristic explains the high prevalence of neonatal jaundice.

The traditional diagnostic method is measuring total serum bilirubin, which requires taking a blood sample. This invasive procedure is painful for the infant, poses an infection risk, and creates difficulties in situations requiring repeated measurements. Furthermore, there is also a visual assessment method, which can only be performed with seventy percent accuracy even by experienced physicians. The lack or limitation of laboratory facilities in resource limited areas severely hinders the timely detection and treatment of neonatal jaundice. Especially in low and middle income countries, one of the main causes of neonatal mortality and morbidity is associated with this exact problem.

In the last decade, artificial intelligence technologies have begun to be widely used in various fields of medicine, including diagnostics, image analysis, and clinical decision making. Non invasive methods based on artificial intelligence in detecting neonatal jaundice are of particular interest because they have the potential to overcome the shortcomings of traditional invasive procedures and make diagnostics more convenient, faster, and cheaper.

Among non invasive methods, optical biosensors, transcutaneous bilirubinometry, and diffuse reflectance spectroscopy hold a special place. Transcutaneous bilirubinometry is based on measuring the amount of bilirubin through the skin, and devices like BiliCheck and J M one zero two Minolta are used in clinical practice. However, these devices are expensive and are either unavailable or not widely used in resource limited areas. Moreover, skin pigmentation, especially in dark skinned infants, can negatively affect the accuracy of measurement results.

The development of artificial intelligence technologies has opened new ways to solve these problems. Machine learning and deep learning algorithms have the ability to analyze complex patterns in neonatal skin color and predict bilirubin levels with high accuracy. Mobile applications analyzing images taken through smartphone cameras have emerged as a convenient and affordable solution that can be used even in resource limited areas. Studies show that artificial intelligence models achieve over ninety percent accuracy compared to traditional methods by applying neural network variants.

The urgency lies in the fact that early detection and treatment of neonatal jaundice is crucial in reducing neonatal mortality and morbidity. Non invasive diagnostic methods based on artificial

intelligence are a promising tool to achieve this goal, and it is necessary to comprehensively study and evaluate their capabilities. The latest scientific achievements in this field are systematically analyzed, and existing challenges and future prospects are discussed.

Objective of the study

To comprehensively analyze and evaluate the capabilities of artificial intelligence based non invasive diagnostic methods in detecting neonatal jaundice. Within the framework of the study, the following tasks were set: to develop a classification of non invasive methods used in detecting neonatal jaundice; to conduct a comparative analysis of different architectures of artificial intelligence models based on their diagnostic accuracy; to study the possibilities of applying smartphone based applications and portable devices in clinical settings; to identify existing challenges and limitations as well as to determine future research directions.

Materials and methods. This study is based on the methodology of systematic literature review. The search strategy was formulated based on keywords such as neonatal jaundice, hyperbilirubinemia, artificial intelligence, machine learning, deep learning, non invasive diagnostics, transcutaneous bilirubinometry, convolutional neural network, vision transformer, and smartphone application.

According to the search results, more than fifty scientific papers published in the period from two thousand ten to March two thousand twenty six were selected.

Among the analyzed studies, there are eighteen traditional machine learning studies, seventeen deep learning studies, thirteen smartphone and non invasive system studies, nine electronic health record based studies, and eight multimodal studies. The applied methods include support vector machine, random forest, extreme gradient boosting, convolutional neural networks, vision transformers, graph neural networks, and capsule networks.

During the data analysis process, the diagnostic accuracy indicators of each study, including sensitivity, specificity, accuracy, area under the curve, mean squared error, and mean absolute error values, were comparatively studied. Furthermore, factors such as the applicability of studies in clinical settings, the size and diversity of datasets, and the extent of covering different skin colors were also analyzed.

Results. Classification of non invasive diagnostic methods. Non invasive methods used in detecting neonatal jaundice can be divided into several categories. The first category includes methods based on optical biosensors. These methods determine the amount of bilirubin by analyzing the reflection spectrum of light sent to the skin. Diffuse reflectance spectroscopy and transcutaneous bilirubinometry are the most commonly used optical methods. Transcutaneous bilirubinometry devices assess bilirubin concentration by sending light to a specific point on the skin and measuring the intensity of the reflected light. Devices such as BiliCheck and J M one zero two Minolta are widely used in clinical practice, but their cost is high, and they are not available in resource limited areas.

The second category includes image based methods. These methods assess the degree of jaundice by analyzing digital images of the skin, sclera, or other body parts. Images taken through smartphone cameras are processed using special algorithms, and the bilirubin amount is predicted. This approach is gaining special attention due to its affordability, convenience, and wide prevalence.

The third category includes multimodal methods. These methods attempt to make more accurate predictions by combining multiple data sources, including images, clinical indicators, and demographic data. For example, along with skin images, factors such as the infant birth weight, gestational age, and postnatal age are also taken into account.

Application of artificial intelligence models. Various machine learning and deep learning models are used in artificial intelligence based non invasive diagnostic methods. Among traditional machine learning methods, support vector machine, random forest, and extreme gradient boosting are the most frequently used algorithms. These models typically rely on manually extracted features and show good results on relatively small datasets.

Deep learning methods, on the other hand, have the ability to automatically learn features from raw data, achieving even higher accuracy. Convolutional neural networks are widely used in image analysis. A one dimensional convolutional neural network approach achieved ninety six and one eighth percent accuracy in predicting bilirubin amounts based on data obtained from Red Green Blue, Hue Saturation Value, Lightness A B, and Luminance Blue Difference Red Difference color spaces. This model was trained on a dataset consisting of two thousand two hundred thirty five images, with a mean squared error value of one point one three and an R squared indicator of zero point nine one.

Vision transformer architectures have shown remarkable results in detecting neonatal jaundice in recent years. The Tokens to Token Vision Transformer model achieved ninety nine percent accuracy, sensitivity, specificity, and area under the curve indicators on a clinically annotated neonatal skin image dataset. This model significantly outperformed other models such as residual networks, support vector machine, and K nearest neighbors. The advantage of the vision transformer is that it can effectively model long term dependencies in an image and has better generalization capabilities compared to traditional convolutional networks.

The capsule graph neural network approach also showed promising results. Optimized with the Wild Horse Algorithm, this model achieved ninety eight point five two percent accuracy. This approach, unlike traditional neural networks, has the ability to preserve the spatial hierarchy of features.

Smartphone based applications. Smartphone based applications hold a special place in screening neonatal jaundice because they use affordable, convenient, and widely available devices. These applications usually take a picture of the infant skin or sclera and predict the amount of bilirubin using special algorithms.

The Bili S G application developed in Singapore uses a machine learning model to predict bilirubin levels in multi ethnic Asian infants. The application is based on the Kramer principle, meaning jaundice spreads on the skin in a specific order, and the amount of bilirubin can be estimated from this pattern. According to the study results, the application achieved a hundred percent sensitivity rate.

The Neo S C B application detects significant jaundice by analyzing pictures taken from the infant sclera. The application evaluates the degree of scleral yellowing using a diagnostic algorithm and presents the result to medical personnel.

The Picterus Jaundice Pro application was studied in a validation study conducted in low resource settings in Oaxaca Mexico. This study aimed to evaluate how the application works in various conditions, including limited lighting and different skin colors.

The mBilimeter device uses artificial intelligence and advanced imaging technology to assess the amount of bilirubin by analyzing pictures of the infant skin. This device was developed for use in resource limited areas where transcutaneous bilirubinometry devices are unavailable or unaffordable.

Accuracy indicators and comparative analysis. The analyzed studies showed that artificial intelligence models achieve high accuracy in detecting neonatal jaundice. Vision transformer architectures showed the best results. The Tokens to Token Vision Transformer model achieved

ninety nine percent across all indicators. The one dimensional convolutional neural network model showed ninety six and one eighth percent accuracy. The capsule graph neural network model achieved ninety eight point five two percent accuracy.

Traditional machine learning methods also showed good results, but their accuracy level was lower compared to deep learning models. Support vector machine and random forest models achieved accuracy ranging from eighty four percent to eighty six point eight three percent.

Studies on improving transcutaneous bilirubinometry results using machine learning have also achieved significant outcomes. A neural network model, by correcting transcutaneous bilirubinometry errors, reduced the root mean square error to one point zero three milligrams per deciliter and the mean absolute error to zero point eight zero milligrams per deciliter in predicting total serum bilirubin. These indicators were zero point three seven and zero point two eight milligrams per deciliter smaller than the specific errors of transcutaneous bilirubinometry itself. It was found that by estimating total serum bilirubin using machine learning, the error decreased by twenty five percent, and the number of unnecessary blood draws could be reduced by up to seventy eight percent.

Challenges and limitations. Despite the success of artificial intelligence based non invasive diagnostic methods, a number of serious challenges remain. One of the most important problems is the impact of skin pigmentation on diagnostic accuracy. Melanin absorbs the light sent to the skin and distorts the reflected signal, which can lead to a significant underestimation of bilirubin levels in dark skinned infants. Studies show that datasets do not have a sufficient number of samples for infants with type five and type six skin colors according to the Fitzpatrick scale. To solve this problem, alternative approaches such as placing sensors under the thumbnail have been proposed, as the melanin amount in this area is relatively low.

The variability of lighting conditions is also a significant problem. Images taken through smartphone cameras are highly sensitive to ambient light, and images taken in different conditions can yield different results even if they have the same amount of bilirubin. Models trained in laboratory conditions may perform worse in real clinical environments due to lighting changes.

The limitation of datasets is another serious problem. Many studies have been conducted on small sized datasets, which limits the generalization ability of the models. For example, some studies used datasets consisting of only one hundred images. Larger and more diverse datasets allow for a better assessment of how models work across different populations.

Model interpretability and clinical trust are also important issues. Deep learning models are often viewed as a black box, meaning it is difficult to understand how they make decisions. This can reduce the trust of physicians in such systems in clinical practice. Explainable artificial intelligence methods aim to solve this problem by providing understandable interpretations of model decisions.

The lack of regulatory approval is also a major barrier. Out of the sixty five analyzed studies, only three meet the thresholds for clinical implementation. Most studies remain in laboratory settings and have not been introduced into real clinical practice. The absence of systems approved by regulatory bodies such as the Food and Drug Administration or the European Union hinders the widespread use of artificial intelligence based diagnostic methods.

Future prospects and solutions. Despite the challenges mentioned above, the future of artificial intelligence based non invasive diagnostic methods looks promising. The federated learning approach allows combining data from different institutions while preserving privacy. Using this method, it is possible to collect larger and more diverse datasets while ensuring patient data confidentiality.

Self supervised and few shot learning paradigms are also promising directions. These methods allow creating models that can work effectively with a limited amount of labeled data. Hyper spectral imaging technology for melanin independent bilirubin sensing is also attracting the attention of researchers.

Multimodal approaches, namely combining different data sources, have the potential to further increase diagnostic accuracy. For example, combining clinical indicators, laboratory results, and demographic data along with skin images allows for more reliable predictions.

Wearable sensors for real time monitoring and continuous transcutaneous bilirubinometry systems may also play an important role in the future. These technologies allow tracking the dynamics of bilirubin levels and assessing the effectiveness of treatment.

Conclusion. Artificial intelligence based non invasive diagnostic methods in detecting neonatal jaundice are one of the most promising areas of modern medicine. This systematic review has shown that artificial intelligence models achieve high accuracy in detecting neonatal jaundice and have a number of advantages over traditional invasive methods.

According to the research results, vision transformer architectures showed the highest outcome, achieving ninety nine percent accuracy across all indicators. One dimensional convolutional neural networks and capsule graph neural networks also achieved over ninety percent accuracy. Smartphone based applications serve as a practical solution in resource limited areas and achieved a hundred percent sensitivity rate in some studies.

Studies on improving transcutaneous bilirubinometry results using machine learning have also achieved significant outcomes. A neural network model reduced the error in estimating total serum bilirubin by twenty five percent and made it possible to reduce the number of unnecessary blood draws by up to seventy eight percent.

At the same time, a number of challenges remain. The impact of skin pigmentation on diagnostic accuracy, variability of lighting conditions, limited datasets, model interpretability, and the lack of regulatory approval are the main problems in this field. To solve these problems, it is necessary to use advanced technologies such as federated learning, explainable artificial intelligence, hyper spectral imaging, and multimodal approaches.

In the future, to widely introduce artificial intelligence based non invasive diagnostic methods into clinical practice, it is necessary to collect larger and more diverse datasets, cover various skin colors, create opportunities for real time monitoring, and accelerate regulatory approval processes. These measures will help reduce neonatal mortality and morbidity through the early detection and treatment of neonatal jaundice.

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