Male Infertility Prediction Model Using Aritificial Neural Network in Surabaya, Indonesia

Ariawan Adimoelja[1*], Sri Andarini[2], Fitri Utaminingrum[3], Tita Hariyanti[4]
[1]*Medical Science Doctoral Program, Faculty of Medicine, Brawijaya University, Malang, Indonesia*
[2]*Department of Public Health Medicine, Faculty of Medicine, Brawijaya University, Malang, Indonesia*
[3]*Department of Informatics Engineering, Faculty of Computer Science, Brawijaya of University, Malang, Indonesia*
[4]*Department of Hospital Management, Faculty of Medicine, Brawijaya University, Malang, Indonesia*
Email: ariawan_a@student.ub.ac.id,dr.sriandarini.fk@ub.ac.id, tita.fk@ub.ac.id, f3.ningrum@ub.ac.id
**Corresponding author. Email:ariawan_a@student.ub.ac.id,*

KEYWORDS
Artificial intelligence, Back Propagation Neural Network, Male infertility, Risk factors

ABSTRACT:
In this study, a fertility clinic in Surabaya, Indonesia, uses artificial neural networks (ANNs) to detect male infertility problems. Despite improvements in fertility diagnostics, there are still issues with precisely forecasting infertility from a variety of patient data collected by non-specific entities. In addition to being inconvenient, male fertility diagnostic techniques like semen analysis, sperm function testing, hormone testing, and genetic testing can also cause discomfort and emotional distress for many patients. The research utilizes a dataset of 260 male patients, divided into training (208 samples) and testing (52 samples) sets, to develop predictive models. Employing a backpropagation neural network (BPNN) model, the study achieved a prediction accuracy performance of 96.6%, highlighting the model's effectiveness in identifying abnormalities in semen parameters linked to male infertility. Key parameters influencing predictions included sperm concentration and morphology, with hypospermia emerging as a significant factor. The results demonstrate that BPNNs can enhance diagnostic precision and facilitate tailored treatment plans for patients, addressing the limitations of traditional diagnostic methods. This innovative approach not only contributes to the understanding of male infertility but also emphasizes the importance of integrating advanced technologies in reproductive health diagnostics. The findings suggest that the implementation of predictive models like BPNNs can significantly improve clinical outcomes for couples facing infertility challenges, paving the way for further research and application in this critical area of healthcare.

INTRODUCTION

The main goal of this study is to predict male infertility problems in patients undergoing sperm analysis at Surabaya clinics using an artificial neural network (ANN). Reduced sperm cell motility and quantity are associated with male infertility issues. People may now evaluate their own sperm thanks to technological advancements, and predictive models are the best way to support early diagnosis in the medical and health fields. In addition, there has already been a great deal of study and use of predictive models (PM) in the fields of assisted reproduction and fertility. Studies that use predictive models for male infertility usually use sperm data obtained from patients who visit an infertility lab run by a particular organization.(Hassan et al., 2020; Inácio Fernandez et al., 2020)There has been no research into predictive modeling based on fertility data from men outside of this organization, especially in Indonesia, where the general population seeks consultation from fertility clinics, hyper-andrology, general andrology, or urologists.(Mas Diyasa et al., 2024)

In the General Hospital Surabaya Fertility Clinic, 916 patients from various regions—including Surabaya, East Java, Bali, NTB, and NTB—were diagnosed with hyperandrology or fertility problems. 3427 outpatients also sought fertility and general andrology services because they were having trouble getting pregnant. 121 male infertility patients were among those who did not obtain treatment at the emergency room. As stated by Musa and Osman (2020), Ni et al. (2021), Ramadhan et al. (2020), and Toufig et al. (2020), Both reproductive clinics and general practitioners referred patients for diseases such microscopic varicocele, oligozoosperm, astenozoosperm, teratozoosperm, azoosperm, and testicular artery investigations.

Generally, these patients were married with or without children. The number and age of patients undergoing fertility therapy were typically four times greater than the number of male infertility patients visiting doctors at the infertility clinics every month, totaling 20-35 cases.(Strasser & Dupree, 2020)

Background of Male Infertility

Male infertility is the inability of the male to cause pregnancy in a fertile female. Male infertility problems can be classified into 6 kinds, such as erectile dysfunction, male contraception, testicular failure, defect in the epididymis or vas deferens, dysfunction of accessory sex glands, and immunologic infertility.(Agarwal, Baskaran, et al., 2021; Pyeritz et al., 2019) The process of male infertility can be caused by various factors, and the diagnosis of the causes of male infertility can be done by conducting an andrology laboratory examination. However, some of these examinations are invasive to the patient.

The object of this study was to make a prediction of infertility problems that occurred in men. There was a total of 260 data in this study and further divided into two datasets; the training set consisted of 208 data of andrology laboratory examinations, and the testing set consisted of 52 data of andrology laboratory examinations. In conclusion, people who get fertility problems can be predicted using an Artificial Neural Network (ANN). Artificial Neural Network's predictive model was evaluated by several performance measurements, such as accuracy, sensitivity, specificity, PPV, NPV, MCC, precision, recall, f1-score, ROC curve, AUC evaluation.(Bui et al., 2020; Chen et al., 2020; Q. feng Liu et al., 2021; Pang et al., 2020) Determination that is carried out using several optimization methods to generate the best increase in the rate of prediction of infertility problems. The nearest two-dimensional parameters of each sex had a predictive error rate of 22%, and the parameters had low fertility rates. In this study, we found many inexperienced factors as male infertility factors as from a literature an annual research study proven around 15-20%. An infertility rate that around 15-20% can be male infertility that is causing pregnancy failure when it is increasingly increasing.(Babakhanzadeh et al., 2020; Mehrjerd et al., 2022; Sharma et al., 2021)

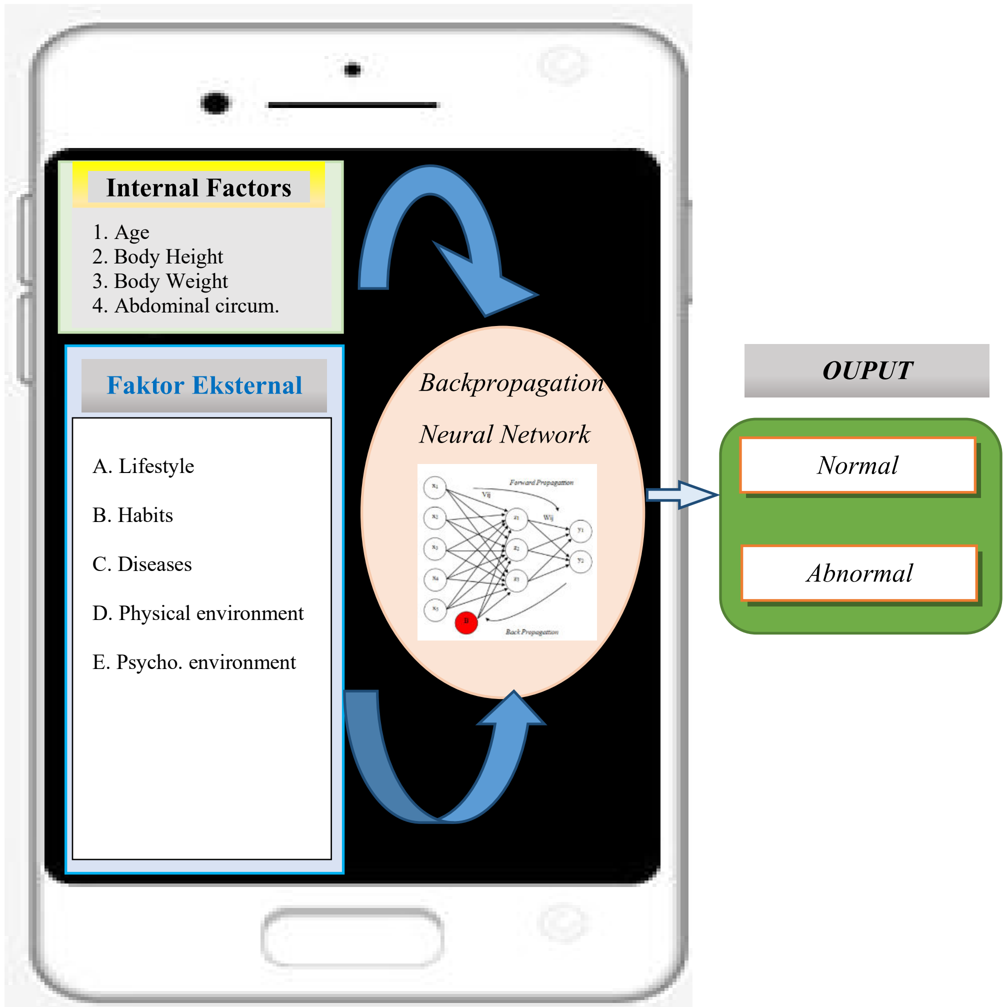
Significance of Predictive Models in Male Infertility Diagnosis

Recent research in artificial intelligence further sensitivity. The prevalence of test men in infertility diagnosis shows that artificial neural bio friends are high enough and have a good degree of accuracy, such as neural networks could overcome the male patients.(Naseem et al., 2023)(Liao et al., 2020)(Inácio Fernandez et al., 2020) The results of this study are expected to help infertility men in general practice, particularly in Surabaya predicted attitudes. This condition is remediable if it is consistently delivered to andrology (male reproduction sub-specialty) infertile men with male infertility factor. Clinic in Surabaya can provide proper evaluation to make a good decision before the doctor takes the medical treatment for the infertile. The application of predictive models in medicine is on the rise. Linear regression analysis was also very popular in medicine, whereas artificial neural networks are a subroutine of the prediction process.

One of the most common uses of these hormones is the prediction of fertility problems in human male infertility. The candidate predictor(s) of researchers believe that neural networks commonly perform better than logistic regression analysis. Corry et al. have previously structured emotional expression. Some men could cry for trivial health events, some others could be just standing in silence despite a significant difference in sperm concentration and 0.65 in their elongated-plus-non-elongated troplets.(Naseem et al., 2023; Prabaharan & Raghunathan, 2021; Shahzad et al., 2023; Yibre & Koçer, 2021)

From literature to Clinical practices

Initial inquiries with fertility experts, specifically Ob-Gyn doctors specializing in fertility, have revealed that the diagnostic approach for male infertility at the several infertility clinics in Surabaya includes a thorough medical history, physical examination, and semen analysis remains consistent. Typically, various parameters such as physical examination of the testes, hormonal assessments, and sperm analysis are routinely conducted. This aligns with research findings indicating that sperm analysis is a key component in diagnosing infertility in both men and women.(Agarwal, Baskaran, et al., 2021; Barbăroșie et al., 2021; Pandruvada et al., 2021; Schlegel et al., 2021a, 2021b)



With a note that in the above research it is possible that the number of expenditure samples is in a variety of public or private infertility clinics in various areas in Indonesia. Then, from another study, it is recommended that research from certain communities needs to be carried out to produce its efficiency, accuracy, and effectiveness. Research-based on communities or donor samples in men's fertility cases and primarily utilizing the ANN process for diagnosis based on sperm may also be categorized as this research logic is in line with research on predicting the likelihood of a man to have prostate cancer using a content-based recommendation system using ANN. In the field of healthcare, the use of ANN in diagnosing male fertility has been carried out through reliability by experts in IVF/ICSI using hybrid ANN optimization, genetic algorithm and branch and bound. ANN has been used for prediction of male fertility by identifying sperm morphology defect using multispectral holographic microscopy.(Almarzouqi et al., 2022; Goyal et al., 2020; Inácio Fernandez et al., 2020; Medenica et al., 2022)

Surabaya, the second-largest city in Indonesia, grapples with the pressing issue of male infertility. The city, known for its robust economy and flourishing healthcare system, is home to over 3 million people, many of whom face challenges with fertility. This concerning pattern has spurred the local infertility clinic to explore inventive strategies for identifying and addressing male infertility issues. In recent times, the utilization of artificial neural networks (ANNs) has emerged as a promising avenue in the realm of reproductive medicine. ANNs, inspired by the intricacies of the human brain, possess the ability to mimic intricate patterns and make precise predictions grounded in extensive data. Armed with this cutting-edge technology, the infertility clinic in Surabaya has embarked on a pioneering quest to leverage the potential of ANNs in forecasting male fertility concerns. The integration of artificial neural networks in the assessment of male infertility marks a significant departure from traditional diagnostic approaches. Previously, male fertility evaluation relied on subjective evaluations and standard tests, often leading to limitations in accuracy and effectiveness. Through the incorporation of ANNs, the clinic aims to revolutionize the diagnostic process by combining state-of-the-art technology with clinical expertise. The primary goal of utilizing ANNs in forecasting male infertility issues is to improve the overall success rates of fertility treatments by precisely identifying the root causes. By examining extensive datasets encompassing parameters such as semen analysis results, hormonal profiles, and medical history, the neural networks can uncover concealed patterns and correlations that may contribute to infertility. These insights empower the clinic's specialists to customize individualized treatment plans, maximizing the likelihood of a favorable outcome for each patient. The implementation of ANN technology has not only attracted the attention of medical professionals but also piqued the interest of researchers and scientists in Surabaya. The potential of ANNs in the field of male infertility prediction has ignited a spirit of collaboration, inspiring interdisciplinary teams to work together in unraveling this complex issue. Through extensive research and rigorous data analysis, these dedicated professionals aim to refine and optimize the ANN models, ensuring higher accuracy and robustness. The use of artificial neural networks in predicting fertility problems has captured significant attention in Surabaya's local infertility clinic. By leveraging this advanced technology, medical experts strive to overcome the challenges posed by male infertility and pave the way for more effective treatments. With continued research and innovations, Surabaya's healthcare system aims to offer hope and solutions to countless couples on their journey towards parenthood.(Bori et al., 2020; Inácio Fernandez et al., 2020; Yibre & Koçer, 2021).

Current Diagnostic Methods for Male Infertility

Male infertility can be assessed by measuring the semen parameters using both microscopic and macroscopic evaluation. Several microscopic evaluations, including the macroscopic parameters results, have to comply with the WHO criteria to identify whether a man is considered infertile. The microscopic and macroscopic measurements might provide the physician with good patient information, but experienced variation between the observers. Some research has tried to overcome the problem by producing accurate and objective results through artificial intelligence methods.(Pakpahan et al., 2023; Pramesemara et al., 2020) Artificial neural network is a type of AI which has been used and gave good results in various medical diagnoses. We identified the main research questions which refer to the data, features, methodologies, and limitations used and described in the reviewed papers. We expect that the current evidence can help the growth of a new approach for male infertility diagnosis.(Agustinus et al., 2020; Darmadi et al., 2024; Pakpahan et al., 2023)

Currently, measuring sperm parameters such as sperm concentration, motility, and morphology are considered as the basic or the first step for assessing male infertility by using either manual techniques or automated semen analyzers. Macroscopic parameters like liquefaction have been used in one third of the included papers, and since 1999, the technique of a microscopist has been using semen analysis to determine the volume. However, semen analysis using the microscope has several weaknesses: it often produces different results between the lab technicians.(Aucky Hinting & Agustinus, 2021; Ismawatie et al., 2021) The Surabaya "Cipto Mangunkusumo" Infertility Clinic has been dedicated to addressing the infertility concerns of our patients for more than three decades. Our clinic has collected approximately

898 semen samples from 388 patients, with 866 samples utilized for training and testing purposes, and the remaining 32 samples utilized for validation. The objective of this research was to forecast infertility issues based on male semen through the utilization of an artificial neural network on the training and testing data.(Darmadi et al., 2024; Ismawatie et al., 2021)

Artificial Neural Networks in Healthcare

Artificial neural networks (ANNs) have been widely utilized across diverse healthcare domains and have garnered favorable responses. They have been applied to a range of diseases and conditions, including those affecting the cardiovascular, digestive, and cognitive systems, among others. Our research employs an ANN to forecast male infertility issues using patient parameters at the Surabaya Infertility Clinic and to identify the most influential parameters. ANNs have demonstrated their efficacy in predicting a wide array of diseases and health conditions. This study is intended to predict male infertility problems that have a relationship with abnormal semen parameters. The performance was tested by comparing between the models used in this study, i.e., Five types of machine learning, including Extreme Learning Machines (ELM) and Random Forest (RF), have been extensively studied for their accuracy. These studies have showcased the effectiveness and potential of ELM and RF algorithms in various applications. Researchers have analyzed the performance of these machine learning techniques in diverse domains such as healthcare, finance, and image recognition, consistently demonstrating their ability to deliver accurate predictions and classifications. Diving deeper into the field, experts have explored the intricacies of ELM and RF, unveiling their unique strengths and limitations. By encompassing a wide range of experiments, research, and practical implementations, the significance of ELM and RF algorithms in machine learning has been well-established, solidifying their position as crucial components in the pursuit of accurate and efficient predictive modeling. (Alsirhani et al., 2023; Rehman et al., 2020; Saputra et al., 2023) If ML is applied in infertility assessment, as long as it is actually interpreted by the physician according to the semen parameters, then this study can be easily analyzed its ability to perform.

At a glance, a new technology related to predicting male infertility problems has been reported; however, our paper still reports the dramatically improved accuracy of predicting male fertility problems using an ANN, by 93.36% based on the data at the Andrology Clinic. This indicates that the majority of male infertility problems are related to some abnormalities in the semen parameters, although there are some CAs that affect male fertility.(Indira et al., 2022; Khan Inan et al., 2021; Mourad et al., 2020) For further results, it clearly proves that the most influential parameter on an abnormality of the semen is a hypospermia category, which is also reported by other papers. Our paper has the strengths in evaluating the semen parameters rather than chromosomal abnormalities (CAs) for an infertility diagnosis, since performing CAs at the first level of fertility diagnosis will be excessively expensive. In addition, our paper has strongly emphasized the prediction of infertility through male semen quality parameters as a straightforward and unbiased analysis to conduct. In our study, we further discussed the importance of determining a standardized value for the semen parameter from three separate time-test samples, enhancing the accuracy and reliability of the evaluation process. This comprehensive approach ensures that our findings are robust and applicable across various clinical settings, making our paper a valuable contribution to the field of male infertility research.(Aghazarian et al., 2021; Keszthelyi et al., 2020; Llavanera et al., 2022; Naseem et al., 2023)

BPNN (Backpropagation Neural Network) is considered to be one of the most prominent and efficient algorithm models in the field of Neural Networks. Its multifaceted applications have made it an extensively utilized tool within the healthcare domain, primarily focusing on the crucial aspects of prediction and diagnosis. Its impactful implementation in the healthcare industry has proven to be highly beneficial, enabling professionals to accurately forecast medical outcomes and provide accurate diagnoses. BPNN's comprehensive capabilities make it an indispensable asset in the realm of healthcare advancements.(Abdolrasol et al., 2021; Al-Jarrah & AL-Oqla, 2022; Samantaray & Sahoo, 2020; Wang et al., 2021; Y. gang Zhang et al., 2021)

The Backpropagation Neural Network has become increasingly popular in the field of artificial intelligence. This powerful algorithm is known for its ability to learn patterns and make predictions based on large datasets. With its complex architecture and efficient training process, BPNN has proven to be a valuable tool in various applications such as image recognition, natural language processing, and financial forecasting. The versatility and accuracy of BPNN have made it a go-to choose for AI researchers and practitioners around the world, pushing the boundaries of what is possible in the realm of machine learning. As technology continues to advance, it is expected that the use of BPNN will only continue to grow, further revolutionizing the field of artificial intelligence.(Kumar & Ramesh, 2023; Madhiarasan & Louzazni, 2022; Thakur, 2021; Xu et al., 2021; Yang & Wang, 2020; C. Zhang & Lu, 2021)

Algorithmic Models in Male Infertility

The current interpretation of a decision support system in the information systems field is known as artificial intelligence. It uses accumulated knowledge and experience to empower computers to make decisions. For instance, specific algorithms have been created for diagnosing various diseases. In the realm of reproductive health, there are no fewer than 15 algorithms commonly utilized to address male infertility.(Hotaling, 2020; Schlegel et al., 2021a, 2021b) These encompass andrological examination analysis, histopathological examination, ultrasonography, digital thermal imaging, hormone levels, anti-sperm antibody, sperm biochemistry, oxidative stress, sperm head, sperm DNA, acrosome reaction of human spermatozoa, transurethral ultrasonography semen analysis, sperm cell gene, examination of married couples, bacteriology, virology, infection specialist assessments, and a host of other advanced diagnostic techniques that have transformed the field and broadened our comprehension of male fertility disorders. These techniques have played a significant role in the development of tailored treatment plans, which take individual factors into consideration and optimize the likelihood of successful conception.(Cardona Barberán et al., 2020; Schlegel et al., 2021a, 2021b; You et al., 2021) As technology continues to advance and knowledge in this field continues to grow, we can anticipate the development of even more sophisticated algorithms and methodologies, further improving the accuracy and precision of male infertility diagnosis and treatment. In the end, the amalgamation of artificial intelligence and decision support systems will continue to shape the future of reproductive health and be crucial in enhancing the quality of healthcare for men globally.(Amann et al., 2022; Belciug & Gorunescu, 2020; Cresswell et al., 2020; Ghayda et al., 2024; Pedersen et al., 2020)

In algorithms that can be used for diagnostic analysis on male infertility, there is an artificial intelligence model that is specifically designed to be able to predict whether males will experience fertility problems in their marriage. This model has a high accuracy level and sets the criteria for inclusion of features based on the results of expert discussion. The concept and method used in this algorithm is that it uses an artificial intelligence approach, particularly using a neural network. This method was involved in the prediction of male infertility problems with high accuracy and was specifically designed to identify how many of the specific andrological disorders would affect the findings.(Ghayda et al., 2024; GhoshRoy et al., 2023a; Mehrjerd et al., 2022; Naseem et al., 2023; Riegler et al., 2021) The AO_FS4 model consists of five mental features noticed from 14 features and main disorders of sperm characteristics. The segmentation guidelines for AI models of male fertility predictions rely on the prediction of an AI man with fertility disorders based on parameters of andrological examination. The AI man, with the help of this advanced and innovative algorithm, is able to accurately detect and analyze numerous factors influencing male infertility. By utilizing the power of artificial intelligence, this algorithm takes into account various parameters from the andrological examination to predict, with utmost precision, the presence of fertility disorders in men. Through the incorporation of a neural network, the AO_FS4 model ensures a high level of accuracy in diagnosing andrological disorders, providing a reliable means of identifying specific issues affecting male fertility. Its robust methodology ensures that the algorithm is able to effectively evaluate the impact of various conditions and abnormalities on sperm characteristics. By following carefully established guidelines, this AI model offers a comprehensive and thorough analysis of male fertility, contributing significantly to the field of reproductive medicine. With its remarkable ability to predict fertility disorders, this algorithm serves as a valuable tool for clinicians and researchers alike, guiding them in the diagnosis and treatment of male infertility. The integration of artificial intelligence with andrological examination parameters has revolutionized the understanding and management of male reproductive health, leading to improved outcomes and advancements in fertility care. As technology continues to advance, the role of AI in reproductive medicine is set to expand, paving the way for further breakthroughs in the field. (Eisenberg et al., 2023)

The utilization of Backpropagation Neural Network (BPNN) in addressing the healthcare concerns pertaining to male infertility has proved to be significantly advantageous. By employing this sophisticated computational model, medical professionals and researchers have been able to delve deeper into the complexities associated with male infertility, enabling them to gain valuable insights for diagnosis, treatment, and overall patient care. The application of BPNN within the realm of male infertility healthcare has emerged as a pioneering approach, empowering healthcare providers to offer comprehensive and targeted solutions to individuals facing these challenges. With its ability to analyze vast amounts of data, identify patterns, and make accurate predictions, BPNN has revolutionized the understanding and management of male infertility, revolutionizing the landscape of reproductive medicine.(GhoshRoy et al., 2023b; Valiuškaitė et al., 2020; Venishetty et al., 2024)

RESEARCH METHOD

This investigation was undertaken in the form of a case study, with data collected from 2018 to 2023 through the documentation of male patients and couples seeking consultation at the Infertility Clinic Center in Surabaya. The focus of the study was on male infertility issues categorized based on semen characteristics, which are vital parameters for defining the quality and quantity of sperm production. Interviewees were selected from male patients with positive medical examination results at the Infertility Clinic, and their data was utilized for the research. Data preparation involved the reduction of irrelevant columns or variables, and the completion of missing values using the mode method. Subsequently, manual if-else conditions were established for male fertility issues in accordance with the criteria proposed by the World Health Organization, whereby "oligozoospermia" was identified if the sperm concentration was less than 15 million cells/mL.(Agarwal, Leisegang, et al., 2021; Schlegel et al., 2020)

The backpropagation neural network used for prediction is composed of a layered structure. The structure comprises artificial neurons and artificial synapses. In the first layer, there are 76 nodes Each node in the first layer receives input from the 80 questions screening male infertility risk factors. The second layer or the so-called hidden layer uses 822 neurons. This layer is responsible for processing the input data and applying weights to calculate the output. Each neuron uses the rectified linear unit activation function. The last layer or the output layer uses only one neuron that receives an input from the neurons of the second layer. We use relu activation to process the procedures. The initial weights are filled with random values. There are 260 male patients who have undergone semen analysis at the clinic. And there are 130 with abnormal sperm analysis others are normal. The selected area under the curve - receiver operating characteristic curve (AUC/ROC) was used as the metric to optimize and select the best model. There are 20% of the data reserved for testing and validation, while the remaining 80% was used for training the model. The results showed that the combination of inputs resulted in an average AUROC of 0.966. The combination of 822 hidden neurons and 1900 epochs can provide an accuracy of 88% and 89% in cross-validation and on an independent test set, respectively. The application is also feasible to use in clinics and/or reproductive health centers that have adequate facilities for collecting and standard examination of semen, especially using computer-assisted semen analysis.

Data Collection and Preprocessing

Given the importance of data in the calculation process, the accuracy and completeness of data will determine the accuracy of the calculation. The data used in this research were obtained from clinical records and validated male infertility risk factors questionnaire at Infertility Clinics in Surabaya and did not contain personal data of the patients in accordance with the clinic's rules. The data obtained still requires further preprocessing before it is used for learning purposes. This preprocessing process is carried out to organize data in a better shape and form. Preprocessing in the form of detailed data is carried out first to get detailed information, find initial patterns and remove oddities or anomalies in the data that have been collected. Then, simplification of data is carried out by selecting data that really has a significant role, does not cause complexity in the learning process, and contain relevant patterns in making predictions using BPNN. The feature selection process is also used as part of data preprocessing.

Preparing for Data Collection, the data is collected as much as 264 records from Infertility Clinics in Surabaya 2018-2023 with the criteria of primary infertility, are not using alternative therapies, have done general examinations and reproductive systems in a clinical and readable form. The initial questionnaire contains 76 major attributes from history taking, physical examination, and seminal examination. The data are processed to remove any inconsistencies or missing values before being used for training the artificial neural network. There are 4 unfullfil led data points that were removed due to incomplete information or errors in recording. There are 260 samples left, which are 130 normozoospermic and 130 abnormal semen analysis results.

Artificial Neural Network Architecture

An artificial neural network consists of a collection of connected units or nodes, called artificial neurons (ANs), that are completely independent individuals with learning ability. The AN model is designed to map inputs to the corresponding outputs. The AN structure is often divided into three parts: input, hidden, and output layers. The amount of input layer nodes and output layer nodes determines the amount of data used for the inputs and the outputs. The width of the hidden layer needs to be determined by training the AN iteratively to reduce the mean squared error of the predicted outputs compared to the expected values of the outputs.

The nodes in the input layer are fully connected to the first hidden layer, so that every input data can go to every node in the first hidden layer. A value of node-layer is inserted into the equation for the first hidden layer using an activation function. The activation function transforms the summed weighted input of nodes to the output of nodes within a certain range. The activation function used for nodes in each hidden layer may vary. This AN consists of six layers, but it is interesting that it uses a different number of nodes and neurons in each layer. The AN used in this study is a super-deep neural network architecture, as it has more than four layers. Deep learning models require essential tuning of a lot of hidden layers based on the given data parameters. The width of the hidden layers needs to be determined by training the AN iteratively to reduce the mean squared error of the predicted outputs compared to the expected values of the outputs.(Lu et al., 2020)(Mao et al., 2020)

Model Training and Validation

The next phase is to perform model training. The main purpose of model training is to train the model to be able to recognize abnormal values from the data included. The most common technique used to train models is to use statistical methods such as backpropagation, a widely used method for model training. The backpropagation process uses an activation function that can be done using fitness values and differentiators of the neural network.

The model validation phase is needed to validate the effectiveness of the AIEV (Artificial Intelligence EValuation) procedure in detecting abnormal semen parameter values in the data. The method is based solely on threshold characteristics and is one way to adjust weight values so that they are more sensitive to the AIEV results.(Boeri et al., 2022; Finelli et al., 2021; Keihani et al., 2021; Li et al., 2021) The AIEV was performed with semen parameter values in the validation dataset. Validation was performed by determining the weight changes in the backpropagation and how the AIEV accuracy values in each case of weight changes.(Cugnetto & Masoero, 2021; Lato, 2023) The obtained findings show that the performance of the ANN model is still quite low to achieve the target accuracy of identifying abnormal values, so it is necessary to conduct optimization in the ANN training phase. All validation of the present

ANN model training procedure was performed with a research protocol that included a male ethical clearance screening stage.(Cugnetto & Masoero, 2021; Lato, 2023; P. Liu & Tung, 2020)

RESULTS AND DISCUSSION

The assessment of predictive model performance in diagnosing male infertility is shown in terms of sensitivity, specificity, precision, and accuracy. In this study, the results and analysis are presented. The evaluation of the prediction ability is obtained using the sensitivity, specificity, precision, and accuracy value. In table 1 presented the confusion matrix of data test, and table 2 mention the classification report according to precision, recall and f1-score results. In general, the selected threshold affects the value of sensitivity, specificity, precision, accuracy, and AUC-ROC value (Figure 1.). And figure 2 is the graph of confusion matrix of the data test. However, because the main goal of this study is to find a model with higher sensitivity to predict fertile men, a threshold that produces higher sensitivity must be chosen.

Table 1. The confusion matrix from data test.

Sperm Analysis	Normal	Abormal	Total
Normal	25	3	28
Abnormal	3	21	24
Total	28	24	52

Tabel 2. Classification report

	Precision	Recall	F1-Score	support
0	0.89	0.89	0.89	28
1	0.88	0.88	0.88	24
Accuracy			**0.88**	52
Macro avg	0.88	0.88	0.88	52
Weighted avg	0.88	0.88	0.88	52

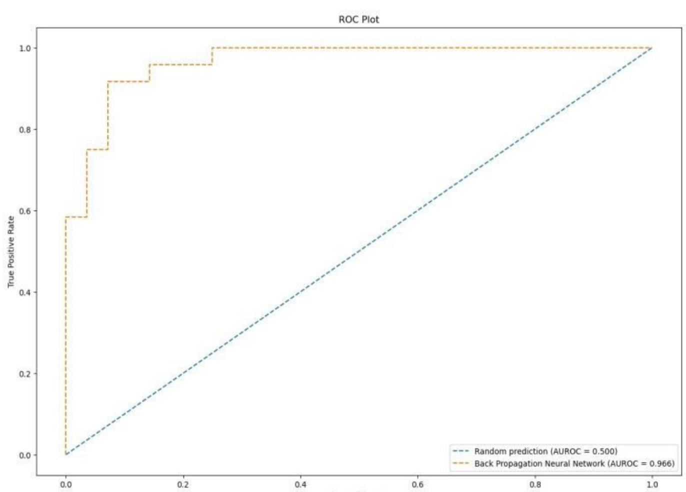


Figure 1. The AUROC graph of BPNN models is 96.6%

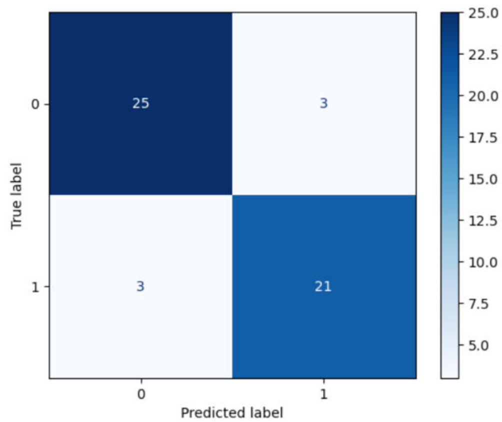


Figure 2. Confusion matrix test diagram

The ROC curve analysis indicates that the AUC of the BPNN's prediction of male fertility according to semen analysis in clinic data has an overall accuracy value of 0.88. Under the curve, we can see that the threshold of sensitivity, specificity, precision, and accuracy is approximately 0.966. The ROC curve shows that the minimum value of sensitivity to predict infertility is 0.88 with high recall as much as 0.89, with precision 89%. This is a better result than traditional diagnostics using the World Health Organization (WHO, 2010)'s standard, where the value of the AUC is only 0.716. It indicates that using the ANN model with biological data to predict male infertility can provide good classification predictions. In this study, the classification prediction used AI with the ANN model, which produces 4 outputs consisting of the values of sensitivity, specificity, precision, and accuracy. Sensitivity is the specificity value used as a medical institution's performance benchmark for predicting male infertility. The analysis showed that when the threshold for the value of 0.7 is generated, the sensitivity is 0.88 (i.e., the best value). Our prediction is 96.6% (i.e., the accuracy value).

Performance Evaluation Metrics

The performance of the predictive model is evaluated using several metrics, which include the confusion matrix and the values of accuracy, sensitivity, and specificity. These evaluation metrics indicate the performance of the predictive model. The confusion matrix is shown in Table 1. Based on the confusion matrix, the numbers of true negative and true positive are 21 and 25, respectively. On the other hand, the numbers of false negative and false positive are 3 and 3, respectively. The predictive model predicts that 25 with abnormal semen analysis and 3 with normal cases are classified correctly.

The values of accuracy, sensitivity, and specificity for the predictive model are approximately 88%, 89%, and 88%, respectively. Accuracy is the proportion of correctly diagnosing the total number of cases and indicates how many male fertility cases are accurately predicted as normal semen analysis results. These results can provide information about the contributions of feature extraction methods for identifying the association between matrix image and the quality of sperm and sperm parameters. All of the diagnosed cases are 88% accurate and only 12% false (false negative and false positive). Moreover, the number of individual sperm parameters used within this experiment is less than the previous study research using feed-forward neural network and Principal Component Analysis, which tested in increasing live births is a total of six parameters of sperm. The six sperm parameters used are as follows: the number of intact acrosomes, abnormal tail, head defects, necrosis, immaturity defect, and immature area.

Comparison with Traditional Diagnostic Methods

Furthermore, to compare with traditional diagnostic methods, it is worth noting that the diagnostic methods for male fertility are semen analysis, sperm function test, hormonal test, and genetic test. These tests are not only inconvenient, but also uncomfortable and can trigger emotional stress and embarrassment for some patients. Hence, this condition can affect the results of fertility tests which require healthy patients. Thus, using Artificial Neural Network (ANN), such as backpropagation neural network, to predict male infertility problems can provide several benefits, namely reducing the percentage of errors in diagnosing male fertility, convenience of reading and diagnosing the test results, and reducing patient discomfort during diagnosis. In comparison with the results in the infertility clinics we used to compare, the numbers and types of attributes are not much different.

In addition, the diagnosis of infertility in men with traditional methods has some weaknesses, including the costly, unpredictable, and lengthy process. During the traditional process, patients must come several times and cause weakness, not only by the patient himself. During the training process using data of 260 patients, the results of predicting the BPNN algorithm diagnostic system as the best system showed that the data score was 88%, with the BPNN algorithm training data showing the accuracy of fertility diagnoses to 88%. The errors given by the system are known to be difficult for experts to understand, and rarely are the pseudoscientists to be reimbursed, to learn how the BPNNs have made this decision or result. In this context, the algorithm BPNN has made it easier to get results or has made the decision-making process.

DISCUSSION

This study suggests that the accuracy of male fertility prediction can be increased using data from factors related to risk factors and assisted reproductive technology (ART). Supervised learning could be used to develop models, such as the BPNN in our study, for predicting male fertility problems based on data from male risk factors and ART. The BPNN model is user-friendly and may support an individual physician in determining the diagnosis and prognosis of infertility. The results of the studies found good accuracy and specificity, which ranged from 88% to 89% in the testing model. Based on these results, we recommend that BPNN is suitable for use in the field of male infertility. However, our study still has several limitations that we intend to discuss.(Cugnetto & Masoero, 2021; Lato, 2023)

The current training consisted of 208 cases (80% of dataset), and the testing model was set using 52 data. As a result, CR increased slightly when the training was conducted. In addition, due to time constraints, we only conducted tests with 52 data and did not compare the two groups. In the future, we will conduct research with the complete data to compare between both abnormal and normal semen analysis groups.

This study shows that the results of the prediction of male fertility using BPNN showed good CR (Classification Rate/Accuracy Rate). In addition, the use of BPNN was user-friendly. High outcome because of the weight and bias error correction in each step of epoch. It is hoped that, by using the tips provided in this study, medical practitioners could easily study research related to male fertility using other methods. However, this study presented several research challenges in conducting the study due to the complexity of the subject and the small sample size. In the future, we hope that studies with large sample sizes with more variable risk factors will be conducted. There are also limitations related to technological indicators and sperm parameters, during which some data need special tests to produce accurate results. In the future, data from technological tests and sperm testing should be accurately collected to improve research. The results of this study also suggested that to achieve a higher accuracy cut-off. These results also showed that further examination is recommended to produce diagnostic results in IUI and ICSI other than normal conceiveness. The results of this study will be used by infertility health care to help predict the infertility of male patients. This study is expected to be an additional reference for researchers who are interested in using digital AI methods to predict male infertility. The study limitations will be a significant increase in CRM (Customer Relationship Management) possibilities if more data are analyzed, and we need alternative tests to confirm the results of the predictive analysis.

Implications of the Study

In clinical practice, diagnosis of male infertility presently requires a semen analysis. However, data preprocessing of computer-assisted sperm analysis is often impractical. As a result, noninvasive tools are explored to determine fertility potential in cheap and practical ways. The use of artificial intelligence using backpropagation neural network (BPNN) is expected to predict male infertility problems without semen analysis. The BPNN is a non-linear statistical data modeling tool using male infertility risk factors. The BPNN tool has superior classification ability and is more precise than others models, therefore it can reduce the level of false positives and false negatives at the classification process, because of the weight and bias error corrections. We expect this BPNN model to be used in conjunction with spermatogenesis markers and ingrained in medical algorithm or diagnostic tool to improve patient care. The BPNN model could have been further improved if we have incorporated environmental pollution HD or urinary cytometry markers, as this BPNN would serve to replace lifestyle advice and pinpoint the source of male infertility as less as possible of the cases.

There is a wide gap in research on the diagnosis of male infertility. Despite their importance in male infertility, most authors advocate the superiority of diagnostic techniques based on cell biology, genomics, and proteomics. This stresses the importance of the use of multiple techniques to achieve a more comprehensive diagnosis of male infertility. Our results confirm the robustness of the BPNN even when it is based on the raw data and is not dependent on the spermatogenesis markers.

Challenges and Limitations

Research in this study only start from 2018 to 2023 because of the data used at the Surabaya Infertility Clinic at that time, and then doctors were reluctant to re-implement the initial patient examination in the application of BPNN. Implementation of this BPNN in a larger and newer population including socio-economic status and post-treatment attitudes at the Surabaya Infertility Clinic. This study was conducted retrospectively using existing secondary data in medical records, questionnaire data, and patient histories available, so it was not possible to obtain incomplete, inaccurate, and biased data. This model implementation can be used only as a prediction so it will need a standard examination process that was used as an input to this study to avoid malpractice in other places.

This model and its validation can only be implemented at the Surabaya Infertility Clinic, and the ability to apply external validation to other populations is still in doubt because the data from the training dataset was minimal and the sensitivity and specificity values showed the ability to predict well. This model is limited to using several variables as the risk factors of male infertility, so improvements are needed using more variables such as the distribution of sperm formation cells, DNA fragmentation test results, and factors such as stress, steroids, and test results on other antipyretics.

CONCLUSION

The study aims to predict the probability of male infertility using a backpropagation neural network model based on male infertility risk factors. Therefore, the parameters were selected using literature studies and based on the availability of the apparatus used. The output of the study is a classification category, which is classified into normal or abnormal semen analysis. The parameters used in the experiments are parameters that have been declared important in proving that a man has a fertility problem. The results showed that BPNN model was highly accurate in predicting male fertility potential in the clinic. Hopefully, the BPNN model can be improved by utilizing other groups of algorithms or sperm condition so that the obtained model can be used more widely.

In future work, more datasets are needed to improve the accuracy of the deep learning BPNN model for this study, so in the future, the neural network algorithm studied is more optimal than before. Furthermore, based on the results of the test datasets used, the need for a model that can be improved to have better output predictions for diagnosing infertility in men. The use of more advanced machine learning techniques such as deep learning algorithms could be explored to enhance the accuracy of the predictive model. Additionally, incorporating genetic data into the model may provide further insights into the underlying causes of male infertility. Basically, if the sperm produced is not good, it will affect female fertility if fertilization is carried out, and pregnancies overshoot in the offspring generated. Therefore, future work can integrate the genes that have been discussed together to produce a genetic panel for quality male reproduction.

REFERENCES

Abdolrasol, M. G. M., Hussain, S. M. S., Ustun, T. S., Sarker, M. R., Hannan, M. A., Mohamed, R., Ali, J. A., Mekhilef, S., & Milad, A. (2021). Artificial Neural Networks Based Optimization Techniques: A Review. *Electronics*, *10*(21), 2689. https://doi.org/10.3390/electronics10212689

Agarwal, A., Baskaran, S., Parekh, N., Cho, C. L., Henkel, R., Vij, S., Arafa, M., Panner Selvam, M. K., & Shah, R. (2021). Male infertility. *The Lancet*, *397*(10271), 319–333. https://doi.org/10.1016/S0140-6736(20)32667-2

Agarwal, A., Leisegang, K., Majzoub, A., Henkel, R., Finelli, R., Panner Selvam, M. K., Tadros, N., Parekh, N., Ko, E. Y., Cho, C.-L., Arafa, M., Alves, M. G., Oliveira, P. F., Alvarez, J. G., & Shah, R. (2021). Utility of Antioxidants in the Treatment of Male Infertility: Clinical Guidelines Based on a Systematic Review and Analysis of Evidence. *The World Journal of Men's Health*, *39*(2), 233. https://doi.org/10.5534/wjmh.200196

Aghazarian, A., Huf, W., Pflüger, H., & Klatte, T. (2021). Standard Semen Parameters vs. Sperm Kinematics to Predict Sperm DNA Damage. *The World Journal of Men's Health*, *39*(1), 116. https://doi.org/10.5534/wjmh.190095

Agustinus, Supardi, Pety Narulita, & Budiono. (2020). The Effectiveness of LenshookeTM Semen Quality Analyzer X1 Pro for Human Semen Analysis. *Indonesian Andrology and Biomedical Journal*, *1*(1), 7–15. https://doi.org/10.20473/iabj.v1i1.26

Al-Jarrah, R., & AL-Oqla, F. M. (2022). A novel integrated BPNN/SNN artificial neural network for predicting the mechanical performance of green fibers for better composite manufacturing. *Composite Structures*, *289*(January), 115475. https://doi.org/10.1016/j.compstruct.2022.115475

Almarzouqi, A., Aburayya, A., & Salloum, S. A. (2022). Determinants predicting the electronic medical record adoption in healthcare: A SEM-Artificial Neural Network approach. *PLoS ONE*, *17*(8 August), 1–29. https://doi.org/10.1371/journal.pone.0272735

Alsirhani, A., Mujib Alshahrani, M., Abukwaik, A., Taloba, A. I., Abd El-Aziz, R. M., & Salem, M. (2023). A novel approach to predicting the stability of the smart grid utilizing MLP-ELM technique. *Alexandria Engineering Journal*, *74*, 495–508. https://doi.org/10.1016/j.aej.2023.05.063

Amann, J., Vetter, D., Blomberg, S. N., Christensen, H. C., Coffee, M., Gerke, S., Gilbert, T. K., Hagendorff, T., Holm, S., Livne, M., Spezzatti, A., Strümke, I., Zicari, R. V., & Madai, V. I. (2022). To explain or not to explain?—Artificial intelligence explainability in clinical decision support systems. *PLOS Digital Health*, *1*(2), e0000016. https://doi.org/10.1371/journal.pdig.0000016

Aucky Hinting, & Agustinus, A. (2021). Technology Updates in Male Infertility Management. *Indonesian Andrology and Biomedical Journal*, *2*(2), 63–67. https://doi.org/10.20473/iabj.v2i2.138

Babakhanzadeh, E., Nazari, M., Ghasemifar, S., & Khodadadian, A. (2020). Some of the Factors Involved in Male Infertility: A Prospective Review. *International Journal of General Medicine*, *Volume 13*, 29–41. https://doi.org/10.2147/IJGM.S241099

Barbăroșie, C., Agarwal, A., & Henkel, R. (2021). Diagnostic value of advanced semen analysis in evaluation of male infertility. *Andrologia*, *53*(2), 1–18. https://doi.org/10.1111/and.13625

Belciug, S., & Gorunescu, F. (2020). *Intelligent Decision Support Systems—A Journey to Smarter Healthcare* (Vol. 157). Springer International Publishing. https://doi.org/10.1007/978-3-030-14354-1

Boeri, L., Fallara, G., Pozzi, E., Belladelli, F., Corsini, C., Raffo, M., Schifano, N., Capogrosso, P., D'Arma, A., Montorsi, F., & Salonia, A. (2022). The impact of different WHO reference criteria for semen analysis in clinical practice: Who will benefit from the new 2021 thresholds for normal semen parameters? *Andrology*, *10*(6), 1134–1142. https://doi.org/10.1111/andr.13213

Bori, L., Paya, E., Alegre, L., Viloria, T. A., Remohi, J. A., Naranjo, V., & Meseguer, M. (2020). Novel and conventional embryo parameters as input data for artificial neural networks: an artificial intelligence model applied for prediction of the implantation potential. *Fertility and Sterility*, *114*(6), 1232–1241. https://doi.org/10.1016/j.fertnstert.2020.08.023

Bui, D. T., Tsangaratos, P., Nguyen, V.-T., Liem, N. Van, & Trinh, P. T. (2020). Comparing the prediction performance of a Deep Learning Neural Network model with conventional machine learning models in landslide susceptibility assessment. *CATENA*, *188*(July 2019), 104426. https://doi.org/10.1016/j.catena.2019.104426

Cardona Barberán, A., Boel, A., Vanden Meerschaut, F., Stoop, D., & Heindryckx, B. (2020). Diagnosis and Treatment of Male Infertility-Related Fertilization Failure. *Journal of Clinical Medicine*, *9*(12), 3899. https://doi.org/10.3390/jcm9123899
Chen, Y., Song, L., Liu, Y., Yang, L., & Li, D. (2020). A Review of the Artificial Neural Network Models for Water Quality Prediction. *Applied Sciences*, *10*(17), 5776. https://doi.org/10.3390/app10175776
Cresswell, K., Callaghan, M., Khan, S., Sheikh, Z., Mozaffar, H., & Sheikh, A. (2020). Investigating the use of data-driven artificial intelligence in computerised decision support systems for health and social care: A systematic review. *Health Informatics Journal*, *26*(3), 2138–2147. https://doi.org/10.1177/1460458219900452
Cugnetto, A., & Masoero, G. (2021). Colored Anti-Hail Nets Modify the Ripening Parameters of Nebbiolo and a Smart NIRS can Predict the Polyphenol Features. *Journal of Agronomy Research*, *4*(1), 23–45. https://doi.org/10.14302/issn.2639-3166.jar-21-3955
Darmadi, D., Pakpahan, C., Singh, R., Saharan, A., Pasaribu, W. S., Hermansyah, H., & Rezano, A. (2024). Inflammatory bowel disease (ulcerative colitis type) severity shows inverse correlation with semen parameters and testosterone levels. *Asian Journal of Andrology*, *26*(2), 155–159. https://doi.org/10.4103/aja202353
Eisenberg, M. L., Esteves, S. C., Lamb, D. J., Hotaling, J. M., Giwercman, A., Hwang, K., & Cheng, Y.-S. (2023). Male infertility. *Nature Reviews Disease Primers*, *9*(1), 49. https://doi.org/10.1038/s41572-023-00459-w
Finelli, R., Leisegang, K., Tumallapalli, S., Henkel, R., & Agarwal, A. (2021). The validity and reliability of computer-aided semen analyzers in performing semen analysis: a systematic review. *Translational Andrology and Urology*, *10*(7), 3069–3079. https://doi.org/10.21037/tau-21-276
Ghayda, R. A., Cannarella, R., Calogero, A. E., Shah, R., Rambhatla, A., Zohdy, W., Kavoussi, P., Avidor-Reiss, T., Boitrelle, F., Mostafa, T., Saleh, R., Toprak, T., Birowo, P., Salvio, G., Calik, G., Kuroda, S., Kaiyal, R. S., Ziouziou, I., Crafa, A., … Agarwal, A. (2024). Artificial Intelligence in Andrology: From Semen Analysis to Image Diagnostics. *The World Journal of Men's Health*, *42*(1), 39. https://doi.org/10.5534/wjmh.230050
GhoshRoy, D., Alvi, P. A., & Santosh, K. C. (2023a). Explainable AI to Predict Male Fertility Using Extreme Gradient Boosting Algorithm with SMOTE. *Electronics (Switzerland)*, *12*(1), 15. https://doi.org/10.3390/electronics12010015
GhoshRoy, D., Alvi, P., & Santosh, K. (2023b). Unboxing Industry-Standard AI Models for Male Fertility Prediction with SHAP. *Healthcare*, *11*(7), 929. https://doi.org/10.3390/healthcare11070929
Goyal, A., Kuchana, M., & Ayyagari, K. P. R. (2020). Machine learning predicts live-birth occurrence before in-vitro fertilization treatment. *Scientific Reports*, *10*(1), 1–12. https://doi.org/10.1038/s41598-020-76928-z
Hassan, M. R., Al-Insaif, S., Hossain, M. I., & Kamruzzaman, J. (2020). A machine learning approach for prediction of pregnancy outcome following IVF treatment. *Neural Computing and Applications*, *32*(7), 2283–2297. https://doi.org/10.1007/s00521-018-3693-9
Hotaling, J. M. (2020). Male Infertility: Is It the Key to the Future of Reproductive Health? *Urologic Clinics of North America*, *47*(2), xiii. https://doi.org/10.1016/j.ucl.2020.01.002
Inácio Fernandez, E., Satoshi Ferreira, A., Henrique Miquelão Cecílio, M., Spinosa Chéles, D., Colauto Milanezi de Souza, R., Fábio Gouveia Nogueira, M., & Celso Rocha, J. (2020). Artificial intelligence in the IVF laboratory: overview through the application of different types of algorithms for the classification of reproductive data. *Journal of Assisted Reproduction and Genetics*, *37*, 2359–2376. https://doi.org/10.1007/s10815-020-01881-9
Indira, D. N. V. S. L. S., Ganiya, R. K., Ashok Babu, P., Xavier, A. J., Kavisankar, L., Hemalatha, S., Senthilkumar, V., Kavitha, T., Rajaram, A., Annam, K., & Yeshitla, A. (2022). Improved Artificial Neural Network with State Order Dataset Estimation for Brain Cancer Cell Diagnosis. *BioMed Research International*, *2022*, 1–10. https://doi.org/10.1155/2022/7799812
Ismawatie, E., Adhipireno, P., Suyono, S. S., Purwanto, E., Santoso, B., & Limijadi, E. K. S. (2021). Differences of Spermatozoa Concentration Analysis Between Manual and Automatic Methods. *Indonesian Journal of Medical Laboratory Science and Technology*, *3*(2), 122–134. https://doi.org/10.33086/ijmlst.v3i2.1961
Keihani, S., Verrilli, L. E., Zhang, C., Presson, A. P., Hanson, H. A., Pastuszak, A. W., Johnstone, E. B., &

Hotaling, J. M. (2021). Semen parameter thresholds and time-to-conception in subfertile couples: how high is high enough? *Human Reproduction*, *36*(8), 2121–2133. https://doi.org/10.1093/humrep/deab133
Keszthelyi, M., Gyarmathy, V. A., Kaposi, A., & Kopa, Z. (2020). The potential role of central obesity in male infertility: Body mass index versus waist to hip ratio as they relate to selected semen parameters. *BMC Public Health*, *20*(1), 307. https://doi.org/10.1186/s12889-020-8413-6
Khan Inan, M. S., Ulfath, R. E., Alam, F. I., Bappee, F. K., & Hasan, R. (2021). Improved Sampling and Feature Selection to Support Extreme Gradient Boosting For PCOS Diagnosis. *2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC)*, *October*, 1046–1050. https://doi.org/10.1109/CCWC51732.2021.9375994
Kumar, P. G., & Ramesh, G. (2023). AN EXPLORATION OF THE POTENTIAL OF DEEP NEURAL NETWORKS IN ARTIFICIAL INTELLIGENCE. *ICTACT JOURNAL ON DATA SCIENCE AND MACHINE LEARNING*, *04*(03), 466–469.
Lato, S. (2023). *Distance-Biregular Graphs and Orthogonal Polynomials by*. University of Waterloo.
Li, J., Hu, T., Wang, Y., Fu, Y., Wang, F., & Hu, R. (2021). Development a nomogram to predict fertilisation rate of infertile males with borderline semen by using semen parameters combined with AMH and INHB. *Andrologia*, *53*(9), 1–9. https://doi.org/10.1111/and.14182
Liao, S., Pan, W., Dai, W., Jin, L., Huang, G., Wang, R., Hu, C., Pan, W., & Tu, H. (2020). Development of a Dynamic Diagnosis Grading System for Infertility Using Machine Learning. *JAMA Network Open*, *3*(11), e2023654. https://doi.org/10.1001/jamanetworkopen.2020.23654
Liu, P., & Tung, Y.-K. (2020). Spatial interpolation of rain-field dynamic time-space evolution based on radar rainfall data. *Hydrology Research*, *51*(3), 521–540. https://doi.org/10.2166/nh.2020.115
Liu, Q. feng, Iqbal, M. F., Yang, J., Lu, X. yang, Zhang, P., & Rauf, M. (2021). Prediction of chloride diffusivity in concrete using artificial neural network: Modelling and performance evaluation. *Construction and Building Materials*, *268*, 121082. https://doi.org/10.1016/j.conbuildmat.2020.121082
Llavanera, M., Delgado-Bermúdez, A., Ribas-Maynou, J., Salas-Huetos, A., & Yeste, M. (2022). A systematic review identifying fertility biomarkers in semen: a clinical approach through Omics to diagnose male infertility. *Fertility and Sterility*, *118*(2), 291–313. https://doi.org/10.1016/j.fertnstert.2022.04.028
Lu, X., Han, D., Duan, L., & Tian, Q. (2020). Intrusion detection of wireless sensor networks based on IPSO algorithm and BP neural network. *International Journal of Computational Science and Engineering*, *22*(2/3), 221. https://doi.org/10.1504/IJCSE.2020.107344
Madhiarasan, M., & Louzazni, M. (2022). Analysis of Artificial Neural Network: Architecture, Types, and Forecasting Applications. *Journal of Electrical and Computer Engineering*, *2022*(i), 1–23. https://doi.org/10.1155/2022/5416722
Mao, Y., Zhou, H., Gui, X., & Shen, J. (2020). Exploring Convolution Neural Network for Branch Prediction. *IEEE Access*, *8*, 152008–152016. https://doi.org/10.1109/ACCESS.2020.3017196
Mas Diyasa, I. G. S., Saputra, W. S. J., Gunawan, A. A. N., Herawati, D., Munir, S., & Humairah, S. (2024). Abnormality Determination of Spermatozoa Motility Using Gaussian Mixture Model and Matching-based Algorithm. *Journal of Robotics and Control (JRC)*, *5*(1), 103–116. https://doi.org/10.18196/jrc.v5i1.20686
Medenica, S., Zivanovic, D., Batkoska, L., Marinelli, S., Basile, G., Perino, A., Cucinella, G., Gullo, G., & Zaami, S. (2022). The Future Is Coming: Artificial Intelligence in the Treatment of Infertility Could Improve Assisted Reproduction Outcomes—The Value of Regulatory Frameworks. *Diagnostics*, *12*(12), 2979. https://doi.org/10.3390/diagnostics12122979
Mehrjerd, A., Rezaei, H., Eslami, S., Ratna, M. B., & Khadem Ghaebi, N. (2022). Internal validation and comparison of predictive models to determine success rate of infertility treatments: a retrospective study of 2485 cycles. *Scientific Reports*, *12*(1), 1–11. https://doi.org/10.1038/s41598-022-10902-9
Mourad, M., Moubayed, S., Dezube, A., Mourad, Y., Park, K., Torreblanca-Zanca, A., Torrecilla, J. S., Cancilla, J. C., & Wang, J. (2020). Machine Learning and Feature Selection Applied to SEER Data to Reliably Assess Thyroid Cancer Prognosis. *Scientific Reports*, *10*(1), 5176. https://doi.org/10.1038/s41598-020-62023-w
Musa, S., & Osman, S. (2020). Risk profile of Qatari women treated for infertility in a tertiary hospital: a case-control study. *Fertility Research and Practice*, *6*(1), 12. https://doi.org/10.1186/s40738-020-00080-5

Naseem, S., Mahmood, T., Saba, T., Alamri, F. S., Bahaj, S. A. O., Ateeq, H., & Farooq, U. (2023). DeepFert: An Intelligent Fertility Rate Prediction Approach for Men Based on Deep Learning Neural Networks. *IEEE Access*, *11*(June), 75006–75022. https://doi.org/10.1109/ACCESS.2023.3290554
Ni, Y., Tong, C., Huang, L., Zhou, W., & Zhang, A. (2021). The analysis of fertility quality of life and the influencing factors of patients with repeated implantation failure. *Health and Quality of Life Outcomes*, *19*(1), 1–10. https://doi.org/10.1186/s12955-021-01666-3
Pakpahan, C., Rezano, A., Margiana, R., Amanda, B., Agustinus, A., & Darmadi, D. (2023). The Association Between Lipid Serum and Semen Parameters: a Systematic Review. *Reproductive Sciences*, *30*(3), 761–771. https://doi.org/10.1007/s43032-022-01040-8
Pandruvada, S., Royfman, R., Shah, T. A., Sindhwani, P., Dupree, J. M., Schon, S., & Avidor-Reiss, T. (2021). Lack of trusted diagnostic tools for undetermined male infertility. *Journal of Assisted Reproduction and Genetics*, *38*(2), 265–276. https://doi.org/10.1007/s10815-020-02037-5
Pang, Z., Niu, F., & O'Neill, Z. (2020). Solar radiation prediction using recurrent neural network and artificial neural network: A case study with comparisons. *Renewable Energy*, *156*, 279–289. https://doi.org/10.1016/j.renene.2020.04.042
Pedersen, M., Verspoor, K., Jenkinson, M., Law, M., Abbott, D. F., & Jackson, G. D. (2020). Artificial intelligence for clinical decision support in neurology. *Brain Communications*, *2*(2), 1–11. https://doi.org/10.1093/braincomms/fcaa096
Prabaharan, L., & Raghunathan, A. (2021). An improved convolutional neural network for abnormality detection and segmentation from human sperm images. *Journal of Ambient Intelligence and Humanized Computing*, *12*(3), 3341–3352. https://doi.org/10.1007/s12652-020-02773-7
Pramesemara, I. G. N., Setiawan, A., Tanojo, T. D., Agustinus, A., & Hartono, J. (2020). Vitamin C and ubiquinone able to maintain sperm telomers length on infertileâ€™s men: a clinical trial at Doctor Soetomo Regional General Hospital, Surabaya, Indonesia. *Bali Medical Journal*, *9*(1), 360–365. https://doi.org/10.15562/bmj.v9i1.1733
Pyeritz, R. E., Korf, B. R., & Grody, W. W. (2019). EMERY AND RIMOIN'S PRINCIPLES AND PRACTICE OF MEDICAL GENETICS AND GENOMICS. In R. E. Pyeritz, B. R. Korf, & W. W. Grody (Eds.), *Academic Press* (Seventh, Vol. 01). Elsevier Inc. https://www.elsevier.com/books-and-journals
Ramadhan, A., Hartono, J., Supardi, P., Pramesti, M. P. B. D., & Lestari, S. W. (2020). Characteristics of erectile dysfunction patients in the andrology unit of Dr. Soetomo Hospital, Surabaya, Indonesia. *Journal of Global Pharma Technology*, *12*(1), 161–166.
Rehman, A., Athar, A., Khan, M. A., Abbas, S., Fatima, A., Atta-ur-Rahman, & Saeed, A. (2020). Modelling, simulation, and optimization of diabetes type II prediction using deep extreme learning machine. *Journal of Ambient Intelligence and Smart Environments*, *12*(2), 125–138. https://doi.org/10.3233/AIS-200554
Riegler, M. A., Stensen, M. H., Witczak, O., Andersen, J. M., Hicks, S. A., Hammer, H. L., Delbarre, E., Halvorsen, P., Yazidi, A., Holst, N., & Haugen, T. B. (2021). Artificial intelligence in the fertility clinic: status, pitfalls and possibilities. *Human Reproduction*, *36*(9), 2429–2442. https://doi.org/10.1093/humrep/deab168
Samantaray, S., & Sahoo, A. (2020). Prediction of runoff using BPNN, FFBPNN, CFBPNN algorithm in arid watershed: A case study. *International Journal of Knowledge-Based and Intelligent Engineering Systems*, *24*(3), 243–251. https://doi.org/10.3233/KES-200046
Saputra, D. C. E., Sunat, K., & Ratnaningsih, T. (2023). A New Artificial Intelligence Approach Using Extreme Learning Machine as the Potentially Effective Model to Predict and Analyze the Diagnosis of Anemia. *Healthcare*, *11*(5), 697. https://doi.org/10.3390/healthcare11050697
Schlegel, P. N., Sigman, M., Collura, B., De Jonge, C. J., Eisenberg, M. J., & Mulhall, J. P. (2020). Diagnosis and Treatment of Infertility in Men: AUA/ ASRM Guideline. *American Society of Reproductive Medicine*, *October*, 1–53.
Schlegel, P. N., Sigman, M., Collura, B., De Jonge, C. J., Eisenberg, M. L., Lamb, D. J., Mulhall, J. P., Niederberger, C., Sandlow, J. I., Sokol, R. Z., Spandorfer, S. D., Tanrikut, C., Treadwell, J. R., Oristaglio, J. T., & Zini, A. (2021a). Diagnosis and Treatment of Infertility in Men: AUA/ASRM Guideline Part I. *Journal of Urology*, *205*(1), 36–43. https://doi.org/10.1097/JU.0000000000001521

Schlegel, P. N., Sigman, M., Collura, B., De Jonge, C. J., Eisenberg, M. L., Lamb, D. J., Mulhall, J. P., Niederberger, C., Sandlow, J. I., Sokol, R. Z., Spandorfer, S. D., Tanrikut, C., Treadwell, J. R., Oristaglio, J. T., & Zini, A. (2021b). Diagnosis and Treatment of Infertility in Men: AUA/ASRM Guideline PART II. *Journal of Urology*, *205*(1), 44–51. https://doi.org/10.1097/JU.0000000000001520

Shahzad, S., Ilyas, M., Lali, M. I. U., Rauf, H. T., Kadry, S., & Nasr, E. A. (2023). Sperm Abnormality Detection Using Sequential Deep Neural Network. *Mathematics*, *11*(3), 515. https://doi.org/10.3390/math11030515

Sharma, A., Minhas, S., Dhillo, W. S., & Jayasena, C. N. (2021). Male infertility due to testicular disorders. *The Journal of Clinical Endocrinology & Metabolism*, *106*(2), e442–e459. https://doi.org/10.1210/clinem/dgaa781

Strasser, M. O., & Dupree, J. M. (2020). Care Delivery for Male Infertility: The Present and Future. *Urologic Clinics of North America*, *47*(2), 193–204. https://doi.org/10.1016/j.ucl.2019.12.006

Thakur, A. (2021). Fundamentals of Neural Networks. *International Journal for Research in Applied Science and Engineering Technology*, *9*(VIII), 407–426. https://doi.org/10.22214/ijraset.2021.37362

Toufig, H., Benameur, T., Twfieg, M. E., Omer, H., & El-Musharaf, T. (2020). Evaluation of hysterosalpingographic findings among patients presenting with infertility. *Saudi Journal of Biological Sciences*, *27*(11), 2876–2882. https://doi.org/10.1016/j.sjbs.2020.08.041

Valiuškaitė, V., Raudonis, V., Maskeliūnas, R., Damaševičius, R., & Krilavičius, T. (2020). Deep Learning Based Evaluation of Spermatozoid Motility for Artificial Insemination. *Sensors*, *21*(1), 72. https://doi.org/10.3390/s21010072

Venishetty, N., Alkassis, M., & Raheem, O. (2024). The Role of Artificial Intelligence in Male Infertility: Evaluation and Treatment: A Narrative Review. *Uro*, *4*(2), 23–35. https://doi.org/10.3390/uro4020003

Wang, H., Hong, M., & Hong, Z. (2021). Research on BP Neural Network Recommendation Model Fusing User Reviews and Ratings. *IEEE Access*, *9*, 86728–86738. https://doi.org/10.1109/ACCESS.2021.3080079

Xu, Y., Liu, X., Cao, X., Huang, C., Liu, E., Qian, S., Liu, X., Wu, Y., Dong, F., Qiu, C.-W., Qiu, J., Hua, K., Su, W., Wu, J., Xu, H., Han, Y., Fu, C., Yin, Z., Liu, M., … Zhang, J. (2021). Artificial intelligence: A powerful paradigm for scientific research. *The Innovation*, *2*(4), 100179. https://doi.org/10.1016/j.xinn.2021.100179

Yang, G. R., & Wang, X. J. (2020). Artificial Neural Networks for Neuroscientists: A Primer. *Neuron*, *107*(6), 1048–1070. https://doi.org/10.1016/j.neuron.2020.09.005

Yibre, A. M., & Koçer, B. (2021). Semen quality predictive model using Feed Forwarded Neural Network trained by Learning-Based Artificial Algae Algorithm. *Engineering Science and Technology, an International Journal*, *24*(2), 310–318. https://doi.org/10.1016/j.jestch.2020.09.001

You, J. B., McCallum, C., Wang, Y., Riordon, J., Nosrati, R., & Sinton, D. (2021). Machine learning for sperm selection. *Nature Reviews Urology*, *18*(7), 387–403. https://doi.org/10.1038/s41585-021-00465-1

Zhang, C., & Lu, Y. (2021). Study on artificial intelligence: The state of the art and future prospects. *Journal of Industrial Information Integration*,*23*(March), 100224. https://doi.org/10.1016/j.jii.2021.100224

Zhang, Y. gang, Tang, J., Liao, R. ping, Zhang, M. fei, Zhang, Y., Wang, X. ming, & Su, Z. yang. (2021). Application of an enhanced BP neural network model with water cycle algorithm on landslide prediction. *Stochastic Environmental Research and Risk Assessment*, *35*(6), 1273–1291. https://doi.org/10.1007/s00477-020-01920-y