Original Article

# Predicting IVF Pregnancy Outcome and Analyzing its Cost Factors: An Artificial Intelligence Approach

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## Abstract

**Background:** Infertility treatment methods that are used today have a limited (or little) success rate, and patients bear a lot of financial and emotional burden to get pregnant. Recently, artificial intelligence has been proposed to evaluate gametes better and choose the best embryo for transfer to the uterus. This study investigated the financial benefit of using artificial intelligence for infertility treatment.

**Materials and Methods:** We aim to evaluate the effectiveness of AI in IVF, comparing AI model performance with standard methods and introducing a novel method to measure financial benefits in healthcare resource allocation.

**Results:** Achieving 75% accuracy, AI significantly outperformed standard methods, reducing the likelihood of discarding viable embryos. This technology streamlines the IVF process, leading to shorter treatment cycles and a cost reduction of 1500 dollars per cycle.

**Conclusion:** The integration of AI in IVF represents a paradigm shift, improving success rates, cost-efficiency, and patient experiences. Further research and adoption of AI-driven embryo selection can revolutionize infertility treatments, benefiting both patients and healthcare systems.

**Keywords:** Embryo selection, Financial benefits, AI-powered embryo selection, In vitro fertilization enhancement, Healthcare cost reduction, Clinical pregnancy prediction

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## Introduction

Approximately 186 million individuals globally are impacted by infertility, with an estimated 8 to 12 percent of couples dealing with this issue[1]. In recent years, in-vitro fertilization (IVF) has become a popular choice for couples seeking to enhance their chances of conception. The IVF process encompasses various stages, including controlled ovarian stimulation, egg retrieval, sperm preparation, fertilization, and embryo culture within a laboratory setting for 1–6 days, followed by the transfer of embryos into the patients' uteruses. Despite notable advancements in IVF technology throughout the past decade, the success rate remains lower than anticipated ([2]). The capacity to choose the best embryo for transplantation has remained relatively unchanged since four decades ago[3]. Merely 10–30% of transplanted embryos culminate in a live birth, often necessitating multiple cycles for patients to achieve pregnancy[4].

The success of IVF cycles is influenced by many factors, encompassing medical diagnosis, maternal age, embryo and gamete quality, and endometrium receptivity. Among these factors, the embryo selection process stands out as a pivotal element in ensuring successful pregnancy and a shortened time to conception for patients[5].

While increasing the quantity of transferred embryos per cycle can heighten the likelihood of pregnancy, it also escalates the risk of multiple pregnancies, a notable concern within Assisted Reproductive Technology (ART). To mitigate this risk, the selection of the optimal embryo and the adoption of Single Embryo Transfer (SET) have demonstrated efficacy in diminishing the occurrence of multiple pregnancies. The most prevalent method for selecting the most suitable embryo involves evaluating embryo morphology under an optical light microscope, conducted by experienced embryologists[6]. However, this approach comes with inherent drawbacks, primarily stemming from its subjective nature and the potential for variability between embryologists with varying levels of expertise[7,8].

Moreover, despite considerable investigation and numerous proposed systems for classifying embryos, a consensus regarding the most dependable approach for foreseeing pregnancy has not yet been achieved. Efforts to enhance embryo assessment have led to the introduction of technologies like the time-lapse imaging (TLI) system, permitting uninterrupted monitoring of embryo development without disturbing its micro-environment. Nonetheless, a substantial degree of variability can exist in embryologists' decisions when opting for the superior embryo using time-lapse images[9]. Additionally, it is important to note that not all IVF laboratories possess access to time-lapse microscopy, and its availability varies for each patient[10].

Due to challenges associated with image-based diagnosis and decision-making, there has been a recent interest in computer-based predictive models that utilize artificial intelligence (AI) to analyze human embryo images[11]. Employing images for a quantitative assessment of embryo parameters promises to enhance success rates, reduce errors, expedite outcomes, and make the process more affordable and accessible. This approach can significantly enhance predicting embryo development and implantation potential accuracy. The AI algorithm could acquire knowledge about the progression of embryo development and leverage this information to select the most viable embryos, thereby enhancing the objectivity of the embryo selection process. The rapidity and uniformity of AI tools make them a consistent asset across all laboratories[12]. Additionally, AI systems might unveil previously undiscovered correlations between various embryo traits.

Recent times have witnessed the utilization of deep learning methodologies, particularly convolutional neural networks (CNNs), to address various challenges in medical imaging. In computer vision, CNNs have risen as the predominant and successful models for image analysis. These techniques have found application in the medical domain, encompassing tasks such as polyp detection and segmentation[13], identification of skin cancer[14], as well as the segmentation and detection of Covid-19-related abnormalities in X-ray images[15,16].

Similarly, a noteworthy interest has emerged in employing machine learning-based algorithms to analyze embryos[17,18]. Researchers in this field have predominantly concentrated on leveraging diverse machine-learning tools to discern the highest-quality embryo based on its potential for successful implantation. Unlike traditional machine learning methods that demand manually crafted features, the novel deep learning algorithms operate without requiring human input, learning intricate features at the pixel level. Embryo evaluation has been approached through two types of data found in IVF laboratories, wherein certain investigations have implemented deep learning algorithms on individual static embryo images[19–21]. Conversely, other studies have applied deep learning to sequences of time-lapse images capturing embryonic development[22–25]. It is important to note that while deep learning techniques exhibit enhanced accuracy when applied to time-lapse images compared to isolated single images, the availability of time-lapse imaging facilities remains limited in most IVF labs.

In this research, we address a critical gap in IVF procedures. Traditionally, the financial benefits of implementing AI in healthcare have been challenging to measure. However, our research pioneers a novel method to quantify the substantial financial advantages of AI utilization in IVF. According to the Iranian Society of Embryology, the average cost of an IVF cycle in Iran is approximately $2,500[26,27]. This innovative approach provides a means to assess the cost reductions and resource optimizations facilitated by AI-driven embryo selection, thus offering valuable insights into the economic implications of this transformative technology.

# Methods

In a retrospective study conducted from July 2017 to February 2020, data were gathered from infertile couples diagnosed at the Research and Clinical Center for Infertility, Yazd Reproductive Sciences Institute, Shahid Sadoughi University of Medical Sciences, Iran. The study was approved by the Research Ethics Committees of Tarbiat Modares University (IR.MODARES.REC.1401.107). The results of our previous study are used to evaluate and compare the success rate of using artificial intelligence-based methods to assess the amount of financial gain. The mentioned study focused on the effectiveness of an AI-based classification algorithm, DeepEmbryo, in predicting clinical pregnancy outcomes in the context of in vitro fertilization (IVF) procedures. The dataset encompassed images taken at regular 10-minute intervals using EmbryoScope® time-lapse imaging equipment, with images captured at 19 ± 1, 44 ± 1, and 68 ± 1 hour's post-insemination. These images were classified into positive or negative samples based on the pregnancy outcomes, with 60% allocated to the training group and 40% forming the test group. Data augmentation techniques were employed, generating 30 augmented samples for each input sample to overcome the limitations of a small dataset.

The study also employed transfer learning, which adapts pre-trained neural network models for specific tasks. Specifically, the last layer of five established pre-trained models, including AlexNet[28], ResNet18[29], ResNet36[29], Inception v3[30], and DenseNet-121[31], were fine-tuned using the limited embryo image dataset.

The DeepEmbryo algorithm employs transfer learning to adapt pre-trained models for embryo classification, addressing the challenge of limited data availability in medical image processing. As in **figure 1**, it operates in two steps: An Image Segmentation Step using the U-Net model to

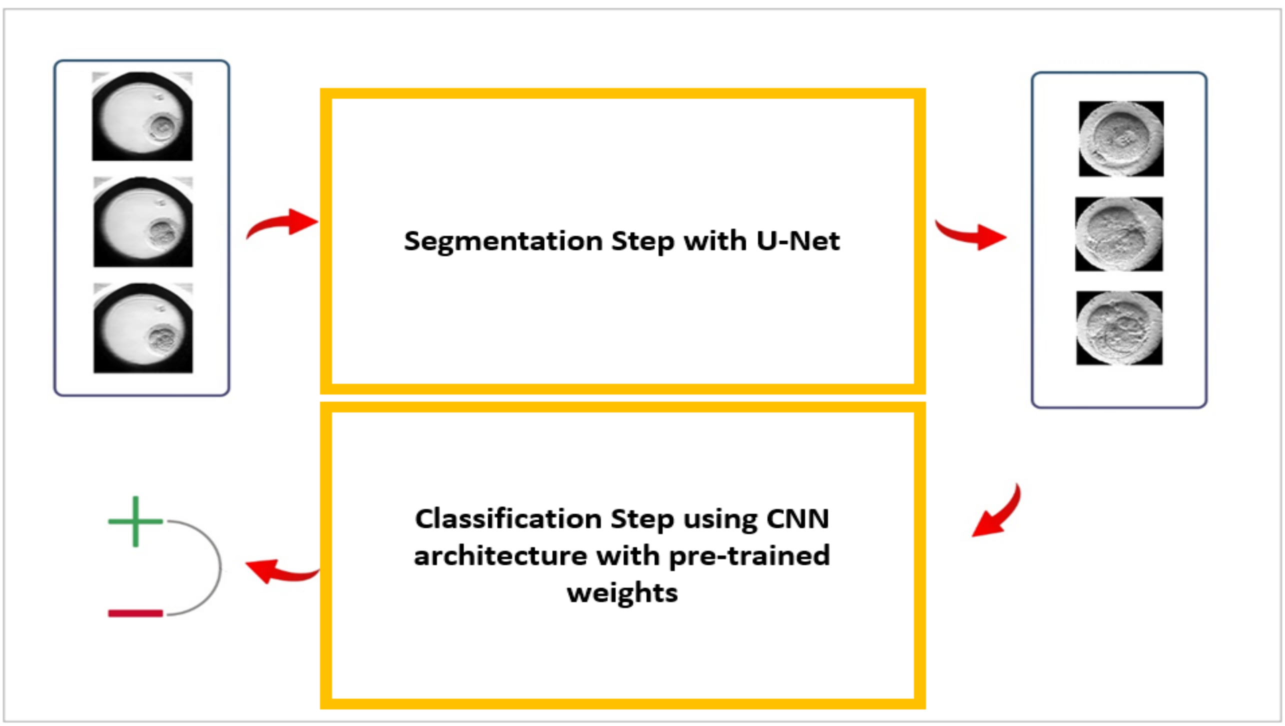


**Figure 1.** DeepEmbryo operates in a two-step fashion. Initially, it divides three input images into distinct segments, identifying the demarcation between embryo components and other image elements. Subsequently, in the second phase of the algorithm, it employs transfer learning alongside the segmented embryos to classify the input embryos.

automate embryo image analysis and a Classification Step using a CNN architecture with pre-trained weights to achieve accurate embryo classification. A streamlined variant, SI-DeepEmbryo, utilizes a single microscopic image and allows for direct performance comparison. Without transfer learning, SI-DeepEmbryo struggles with limited accuracy, while DeepEmbryo, leveraging transfer learning, excels at 75.0% accuracy. DeepEmbryo's segmentation step effectively distinguishes embryos, and its classification step excels in predicting pregnancy outcomes across different CNN architectures.

**Table 1** further underscores the superiority of DeepEmbryo over SI-DeepEmbryo across various CNN architectures, particularly when using pre-trained Inception V3. DeepEmbryo outperforms SI-DeepEmbryo by substantial margins: 8.33% in Accuracy, 10.94% in Precision, and 8.33% in Recall. These findings underscore the significant benefits of Transfer Learning in improving the classification accuracy of embryo images, with DeepEmbryo emerging as the superior choice within this context.

**Table 1:** DeepEmbryo Results with Different Architectures and Transfer Learning.

| | AlexNet | ResNet 18 | ResNet 34 | Inception V3 | DenseNet 121 |
|---|---|---|---|---|---|
| Recall (%) | 66.66 | 75.00 | 69.88 | **75.00** | 69.44 |
| Precision (%) | 76.00 | 75.71 | 69.93 | **79.45** | 72.90 |
| Accuracy (%) | 66.66 | 75.00 | 69.88 | **75.00** | 69.44 |

# Results

Implementing a Convolutional Neural Network (CNN) based model for embryo classification can significantly alleviate financial burdens within the healthcare system. Hospitals can realize substantial cost savings by seamlessly integrating this advanced technology into the infertility treatment procedure. Firstly, the CNN model's accurate classification of embryos ensures a more efficient selection process, resulting in a higher likelihood of successful pregnancies. Consequently, patients are more likely to achieve successful outcomes in a shorter timeframe, reducing the need for repeated treatment cycles. It enhances patient satisfaction and reduces the strain on medical resources, curbing the associated costs of prolonged treatments and multiple attempts.

Furthermore, utilizing the CNN model in embryo classification offers a streamlining effect on hospital workflows. The automated and objective assessment of embryos eliminates the subjectivity inherent in manual evaluation methods. It enhances the precision of embryo selection and expedites decision-making, reducing the time embryos spend in culture and optimizing resource allocation. Moreover, reducing human intervention minimizes the likelihood of errors, leading to a decline in unnecessary procedures, repeated tests, and related expenses. Ultimately, by leveraging the CNN model's capabilities, healthcare institutions can witness a transformative shift in their approach to infertility treatment, leading to substantial cost reductions while simultaneously improving patient outcomes and experiences. The development of this model and its exploitation can lead to the following improvements:

**Improved Treatment Quality** Implementing the deep learning embryo classification model can enhance the treatment quality by aiding embryologists in making more accurate decisions. It leads to a higher proportion of good embryos being selected for transfer, increasing the chances of successful pregnancies. With a recall of 75%, the model can accurately identify 75% of embryos that would have resulted in successful pregnancies, minimizing the risk of discarding viable embryos. Similarly, the precision of 79.45% ensures that a significant proportion of embryos selected as "good" are likely to result in successful pregnancies, reducing the possibility of unnecessary transfers.

**Cost Reductions** The financial implications of employing this deep learning model are substantial. As it was mentioned before, the average cost of an IVF cycle in Iran is about $2,500. The model's accuracy at 75% outperforms the common methods, achieving a success rate of 55.6%[32]. The increase in accuracy translates to a reduction in unsuccessful IVF cycles, consequently saving both patients and the healthcare system significantly. In direct costs, a single IVF cycle can cost the healthcare system around $1,200 due to the

**Table 2:** Cost Reduction Resulting from Implementing AI-based methods.

| | Average Accuracy (%) | Average cost per Cycle ($) | Expected Cost of a Successful Cycle |
|---|---|---|---|
| Deep Learning Model | 79.45 | 2500 | 3147 |
| Common Method | 55.60 | 2500 | 4496 |
| The Difference | 23.85 | 0 | 1349 |

resources required for laboratory procedures, consultations, and medications. By reducing the number of unsuccessful cycles, the model can potentially lead to an estimated 25% reduction in direct costs per cycle, saving the healthcare system substantial amounts annually. Table 2 shows that using our deep learning model instead of Embryologists can reduce the expected cost of a successful cycle by about 1349 dollars. However, excessively depending on the model's suggestions could reduce their clinical judgment and expertise. Finding the right equilibrium between AI assistance and human decision-making is essential to guarantee holistic patient care.

**Reduced Patient Burden and Resource Allocation:** Beyond direct cost savings, the model can reduce patients' emotional and financial burdens. With an improved accuracy of embryo selection, patients are more likely to experience successful pregnancies in fewer cycles. It reduces the number of cycles patients need to undergo, saving them money and reducing emotional stress. Additionally, the model optimizes resource allocation by minimizing the utilization of costly resources on embryos that are unlikely to result in pregnancies. This results in better allocation of laboratory and medical staff time, space, and materials, contributing to the overall efficiency of the hospital and health system. An overview of the mentioned benefits is described in Figure 2.

## Discussion

This study addresses a crucial aspect of infertility treatment by exploring the financial benefits of incorporating artificial intelligence (AI), particularly deep learning models, into the in-vitro fertilization (IVF) process. The introduction aptly highlights the substantial emotional and financial burdens borne by patients undergoing infertility treatment. Despite advancements in IVF, the success rates remain limited, and the selection of the most viable embryo for transfer represents a significant challenge, leading to extended treatment cycles and associated costs.

The study's significance is evident in its novel approach to evaluating AI's financial benefits in healthcare resource allocation, particularly within the context of IVF. The research leverages AI to streamline embryo selection, significantly improving treatment quality, financial savings, and overall patient experience.

The first key finding emphasizes that AI significantly outperforms common methods with an impressive 75% accuracy, addressing one of the pivotal issues in the IVF process - embryo selection. By minimizing the risk of discarding viable embryos, AI enhances treatment efficacy and reduces the emotional stress on patients.

Financial implications play a central role in this research. The study demonstrates that integrating AI results in a cost reduction of approximately $1,349 per cycle compared to traditional methods. These financial savings are twofold: firstly, a direct cost reduction by avoiding unnecessary IVF cycles and, secondly, an indirect cost reduction through streamlined hospital workflows. The automated and objective assessment of embryos minimizes errors, reduces the time embryos spend in culture, and optimizes resource allocation. These measures lead to substantial cost reductions for healthcare institutions, ultimately benefiting patients and the healthcare system.

In addition to direct financial savings, the model alleviates patients' emotional and financial burdens. By increasing the accuracy of embryo selection, patients are more likely to achieve successful pregnancies in fewer cycles. It reduces the number of cycles patients need to undergo and improves their overall experience, mitigating emotional stress and financial strain.

The study's approach to integrating deep learning and transfer learning in embryo classification holds promise. AI provides consistent and objective support across different laboratories, reducing the variability inherent in human assessments. Moreover, the flexibility to employ various CNN architectures tailors the AI to specific needs, thereby contributing to the accuracy of pregnancy outcome predictions.

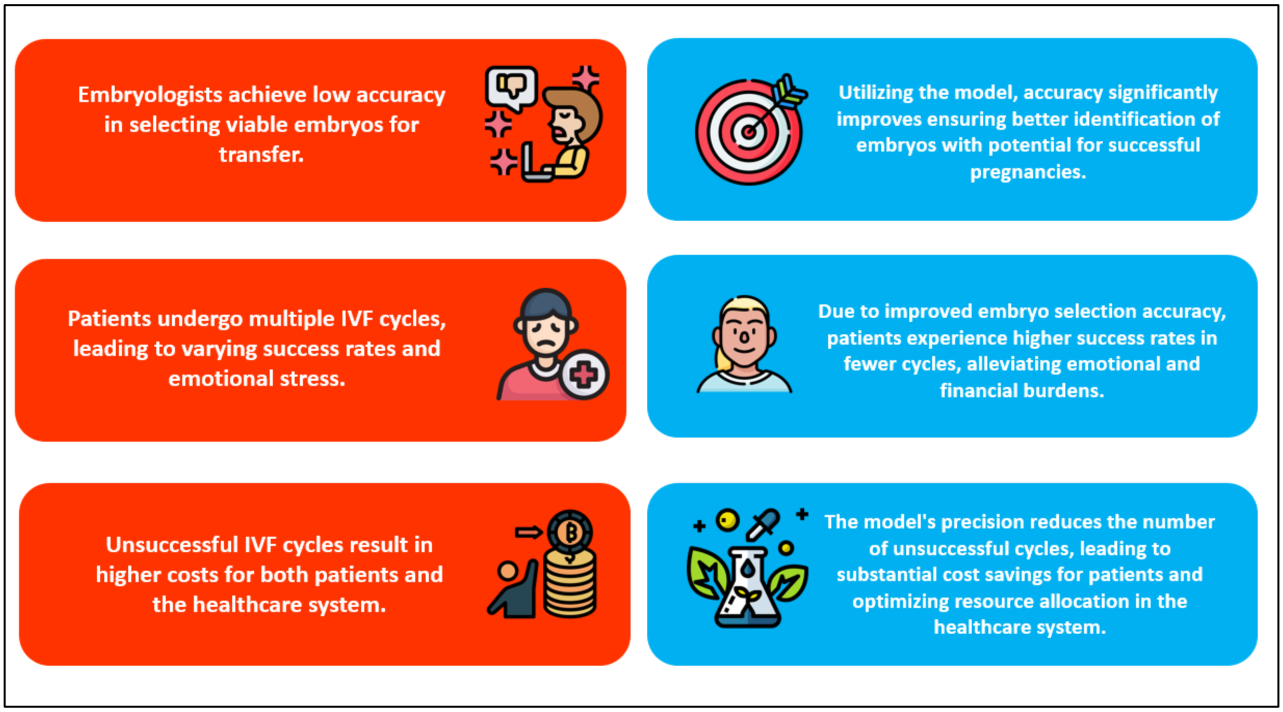


**Figure 2.** Provided benefits of implementing DeepEmbryo.

The study's findings suggest a transformative shift in infertility treatment. Infertility treatments have become more cost-effective, efficient, and patient-centric by harnessing AI. This research paves the way for further exploration and adoption of AI-driven embryo selection, potentially revolutionizing the IVF landscape and enhancing patient experiences and healthcare systems.

In summary, this study demonstrates that AI-powered embryo selection offers a range of significant benefits. Integrating AI improves treatment quality, significantly reduces costs, and eases patients' emotional and financial burdens. Furthermore, it streamlines resource allocation within healthcare institutions. Overall, the results underscore the potential of AI to reshape infertility treatments for the better.

## Conclusion

In conclusion, this study underscores the transformative potential of artificial intelligence, specifically the DeepEmbryo algorithm, in embryo selection for infertility treatments. Through rigorous evaluation, we have demonstrated that DeepEmbryo, empowered by transfer learning, offers a superior level of accuracy in predicting clinical pregnancy outcomes when compared to both human embryologists and a variant of the model, SI-DeepEmbryo. The implementation of DeepEmbryo can bring about substantial improvements in the quality of infertility treatments, as it enables embryologists to make more accurate decisions, leading to a higher proportion of successful pregnancies and a reduced risk of discarding viable embryos. Beyond its clinical impact, adopting AI-based embryo selection also holds significant financial implications. By minimizing the number of unsuccessful IVF cycles and optimizing resource allocation, healthcare institutions can realize considerable cost savings, benefiting the healthcare system and patients. Moreover, reducing the emotional and financial burden on patients is a profound outcome of this technology, offering them a more efficient path to successful pregnancies and reducing the number of treatment cycles required. In summary, integrating artificial intelligence into infertility treatment procedures represents a significant advancement in the field. Further research and clinical integration are warranted to fully harness the potential of AI-driven embryo selection in real-world healthcare settings, ultimately improving patient outcomes and experiences while optimizing resource utilization within healthcare systems.

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## Conflict of interest

The authors further declare that they have no conflict of interest.

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