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TRANSFER LEARNING FOR BINARY PNEUMONIA CLASSIFICATION FROM CHEST X-RAY IMAGES: A COMPARATIVE STUDY OF DENSENET121, DENSENET169, AND DENSENET201

Mukhriddin Arabboev
Associate Professor, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi
Email: mukhriddin.arabboev@tuit.uz
Shohruh Begmatov
Associate Professor, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi
Email: sh.begmatov@tuit.uz
Sukhrob Bobojanov
Associate Professor, Urgench Ranch University of Technology
Email: dr.bobojanov@ranch.university
Akhram Nishanov
Professor, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi
Email: a.nishanov@tuit.uz

Abstract. This paper presents a comparative study of three DenseNet-based transfer learning models for binary pneumonia classification from chest X-ray images. DenseNet121, DenseNet169, and DenseNet201 were evaluated under a unified framework using ImageNet-pretrained backbones, a lightweight classification head, online augmentation, two-stage optimization, and validation AUC-based early stopping. All images were resized to 224 × 224 pixels and divided into training, validation, and test subsets. The test set contained 587 radiographs, including 159 NORMAL and 428 PNEUMONIA cases. DenseNet169 achieved the best overall performance, with 93.70% accuracy, 0.9796 AUC, and 96.88% precision. DenseNet121 showed similarly strong results with slightly higher sensitivity, while DenseNet201 achieved the highest sensitivity (98.36%) but substantially lower specificity. These findings indicate that DenseNet169 provides the most balanced performance for binary pneumonia screening, whereas DenseNet201 may be more suitable when minimizing missed pneumonia cases is the primary priority.

Keywords: pneumonia detection; chest radiography; DenseNet; transfer learning; deep learning; medical image analysis

Аннотация. В данной работе представлено сравнительное исследование трёх моделей переноса обучения на основе DenseNet для бинарной классификации пневмонии по рентгеновским изображениям грудной клетки. Модели

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DenseNet121, DenseNet169 и DenseNet201 были оценены в рамках единого подхода с использованием предобученных на ImageNet базовых архитектур, облегчённой классификационной головы, онлайн-аугментации, двухэтапной оптимизации и ранней остановки на основе значения AUC на валидационной выборке. Все изображения были приведены к размеру 224 × 224 пикселя и разделены на обучающую, валидационную и тестовую подвыборки. Тестовая выборка содержала 587 рентгенограмм, включая 159 случаев NORMAL и 428 случаев PNEUMONIA. Наилучшие суммарные результаты показала модель DenseNet169: точность 93,70%, AUC 0,9796 и precision 96,88%. Модель DenseNet121 продемонстрировала сопоставимо высокие результаты при немного более высокой чувствительности, тогда как DenseNet201 обеспечила наибольшую чувствительность (98,36%), но существенно более низкую специфичность. Полученные результаты показывают, что DenseNet169 обеспечивает наиболее сбалансированную эффективность для бинарного скрининга пневмонии, тогда как DenseNet201 может быть более предпочтительной в случаях, когда главным приоритетом является минимизация пропущенных случаев пневмонии.

Ключевые слова: выявление пневмонии; рентгенография грудной клетки; DenseNet; перенос обучения; глубокое обучение; анализ медицинских изображений

Annotatsiya. Ushbu maqolada ko‘krak qafasi rentgen tasvirlari asosida pnevmoniyani ikkilik sinflashtirish uchun DenseNet asosidagi uchta transfer learning modeli qiyosiy tahlil qilindi. DenseNet121, DenseNet169 va DenseNet201 modellarining samaradorligi yagona yondashuv asosida baholandi; bunda ImageNetda oldindan o‘qitilgan tayanch arxitekturalar, yengil sinflashtirish qatlami, onlayn augmentatsiya, ikki bosqichli optimallashtirish hamda validatsiya tanlanmasidagi AUC ko‘rsatkichiga asoslangan erta to‘xtatish usuli qo‘llanildi. Barcha tasvirlar 224 × 224 piksel o‘lchamga keltirildi va o‘qitish, validatsiya hamda test to‘plamlariga ajratildi. Test to‘plami 587 ta rentgen tasviridan iborat bo‘lib, ulardan 159 tasi NORMAL va 428 tasi PNEUMONIA sinfiga tegishli bo‘ldi. Eng yaxshi umumiy natijani DenseNet169 modeli ko‘rsatdi: aniqlik 93.70%, AUC 0.9796 va precision 96.88%. DenseNet121 ham shunga yaqin yuqori natijalarni namoyish etdi va uning sezgirligi biroz yuqoriroq bo‘ldi, DenseNet201 esa eng yuqori sezgirlikka (98.36%) erishgan bo‘lsa-da, uning xoslik ko‘rsatkichi sezilarli darajada past bo‘ldi. Olingan natijalar DenseNet169 modeli pnevmoniyani ikkilik skrining qilish uchun eng muvozanatli samaradorlikni ta’minlashini, DenseNet201 esa pnevmoniya holatlarini o‘tkazib yuborishni minimallashtirish

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ustuvor bo‘lgan vaziyatlarda maqsadga muvofiqroq bo‘lishi mumkinligini ko‘rsatdi.

Kalit so‘zlar: pnevmoniyani aniqlash; ko‘krak qafasi rentgen tasviri; DenseNet; transfer learning; chuqur o‘qitish; tibbiy tasvirlar tahlili

1. INTRODUCTION.

Chest X-ray imaging remains one of the most accessible and clinically important tools for the first-line assessment of thoracic disease, including pneumonia. However, visual interpretation can be affected by workload, inter-reader variability, and the subtle overlap between infectious and non-infectious radiographic patterns. For these reasons, deep learning-based computer-aided diagnostic systems continue to attract attention as decision-support tools for screening and prioritization [1], [2], [5]. Dense convolutional networks are particularly attractive for medical image classification because they encourage feature reuse through direct connections between layers, which can improve gradient flow and reduce parameter redundancy compared with conventional deep convolutional designs [3]. The present study employs three representative DenseNet backbones—DenseNet121, DenseNet169, and DenseNet201—within a transfer-learning framework for binary classification of chest radiographs into NORMAL and PNEUMONIA categories.

Rather than proposing a new network architecture, the objective of the present study is to provide a controlled comparative analysis of three DenseNet variants under a unified transfer-learning framework for binary pneumonia classification. The study is based on a consistent experimental protocol and a preserved summary of test predictions and performance indices. On this basis, the paper presents the study design, compares the three models under a common methodological framework, interprets confusion-matrix patterns and receiver operating characteristics, and identifies the most suitable model for balanced pneumonia detection on the test set.

2. BACKGROUND AND RELATED WORK

DenseNet was introduced to improve information and gradient flow by concatenating features from all preceding layers into each subsequent layer [3]. This design has become influential in medical imaging because transfer learning from ImageNet-pretrained DenseNet backbones often yields strong performance with moderate model-development effort [3], [4].

In chest X-ray analysis, prominent benchmarks and studies such as ChestX-ray8 and CheXNet demonstrated that deep convolutional models can learn diagnostically useful patterns from radiographs and can achieve competitive performance for pneumonia-related tasks [2], [5]. Publicly distributed pneumonia

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datasets derived from pediatric chest radiographs have further enabled smaller-scale binary classification studies in which transfer learning is especially practical [1].

The present study belongs to this family of transfer-learning approaches. Its practical value lies in a controlled comparison of three DenseNet variants under identical preprocessing, augmentation, optimization, and stopping conditions. This design allows the effect of model depth to be observed more clearly than in studies where the full pipeline changes across models.

3. MATERIALS AND METHODS

3.1 Experimental protocol and reproducibility

The present study follows a documented experimental protocol and a consolidated multi-model performance summary. The study protocol incorporates a fixed random initialization strategy and deterministic execution settings in order to improve reproducibility across runs. The experimental workflow was designed to train the selected models and subsequently generate a unified summary containing test predictions, confusion matrices, and evaluation metrics.

Figure 1 illustrates the overall methodology adopted for binary pneumonia classification from chest X-ray images using transfer learning with DenseNet models.

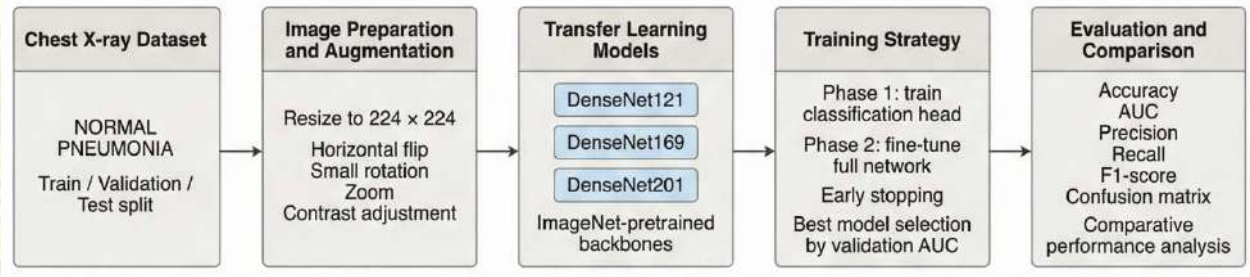


Figure 1. Overall methodology for binary pneumonia classification from chest X-ray images using transfer learning with DenseNet models.

3.2 Dataset organization

The experimental design follows a structured dataset organization with separate training, validation, and test partitions, each containing two diagnostic categories: NORMAL and PNEUMONIA. The study was conducted on a publicly available chest X-ray dataset for pediatric pneumonia classification [1]. All images were processed as three-channel chest radiographs with binary labels at a fixed spatial resolution of 224 × 224 pixels. The preserved test summary indicates that the held-out test set contained 587 images, consisting of 159 NORMAL and 428 PNEUMONIA samples. This distribution is imbalanced in favor of pneumonia, which is important for interpreting sensitivity, specificity, and false-positive behavior.

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3.3 Data pipeline and augmentation

The data preparation strategy incorporates a lightweight online augmentation scheme intended to improve generalization. The applied transformations include horizontal reflection, small-angle rotation, moderate zoom variation, and mild contrast adjustment. In addition, the input workflow was organized to ensure consistent handling of the training, validation, and test partitions. This design is appropriate for practical model development because it limits unnecessary computational burden while preserving methodological simplicity.

3.4 Model architecture

Each experiment employed one ImageNet-pretrained DenseNet backbone—DenseNet121, DenseNet169, or DenseNet201—to extract high-level visual representations from chest radiographs. A compact classification head was then attached to the extracted representation, consisting of a dropout layer with a rate of 0.3 and a single sigmoid output unit for binary prediction. This design keeps the classifier parsimonious and ensures that the comparative analysis depends primarily on the representational capacity of the selected backbone.

3.5 Training strategy

Model development was conducted in two consecutive phases. In the first phase, the backbone parameters were held fixed and only the classification layer was optimized using an initial learning rate of 1×10^{-3}. In the second phase, the full network was fine-tuned with a reduced learning rate of 1×10^{-4}. The transition to fine-tuning was introduced after an initial warm-up stage, allowing task-specific adaptation before full-network optimization. In both phases, the best-performing model state was preserved, and training was terminated early when the validation AUC failed to improve for five consecutive epochs. This strategy is well suited to imbalanced binary classification because AUC is less affected than raw accuracy by skewed class frequencies.

3.6 Evaluation metrics

For final evaluation, the study generated binary predictions using a fixed decision threshold of 0.5 and reported test accuracy, ROC AUC, positive-class precision, positive-class recall, positive-class F1-score, and the confusion matrix. From the confusion matrices, additional clinically relevant measures can also be derived, particularly specificity and balanced accuracy. These secondary indicators are especially informative because the test set is class-imbalanced.

4. RESULTS

Section 4 presents the comparative performance of DenseNet121, DenseNet169, and DenseNet201 on the held-out test set for binary pneumonia classification. The results are analyzed using standard evaluation metrics, including

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accuracy, AUC, precision, sensitivity, specificity, and F1-score, together with ROC curves, confusion matrices, and comparison with selected existing studies. The quantitative performance of the evaluated DenseNet variants on the held-out test set is presented in Table 1.

Table 1

Quantitative comparison of the DenseNet variants on the held-out test set.

Model	Accuracy	AUC	Precision	Sensitivity	Specificity	F1-score
DenseNet121	93.36%	0.9785	95.13%	95.79%	86.79%	95.46%
DenseNet169	**93.70%**	**0.9796**	**96.88%**	94.39%	**91.82%**	**95.62%**
DenseNet201	90.12%	0.9703	89.19%	**98.36%**	67.92%	93.56%

As shown in Table 1, DenseNet169 achieved the best overall performance among the three evaluated models, with the highest accuracy, AUC, precision, specificity, and F1-score. DenseNet121 was only marginally weaker and remained highly competitive. DenseNet201 achieved the highest sensitivity but produced more false-positive normal-to-pneumonia predictions, which reduced its accuracy and specificity.

To further contextualize the performance of the proposed models, Table 2 compares the best-performing model in the present study with selected existing studies conducted on pediatric or Kermany-style pneumonia chest X-ray datasets. As shown, DenseNet169 achieved competitive performance and outperformed several reported methods in terms of classification accuracy. However, these comparisons should be interpreted cautiously because dataset splits, preprocessing procedures, and evaluation protocols differ across studies.

Table 2

Comparison with selected existing studies on pneumonia chest X-ray classification.

Study	Year	Dataset	Model / Method	Accuracy
Kermany et al. [1]	2018	Pediatric chest X-ray dataset	Deep learning diagnosis framework	92.80%
Ortiz-Toro et al. [6]	2022	Pediatric chest X-ray dataset	Superpixel-based feature extraction + ML	91.30%
Alshanketi et al. [7]	2024	Pneumonia chest X-ray dataset	VGG16 + augmentation + class weighting	91.00%

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Sharma and Guleria [8]	2023	Pediatric pneumonia dataset	VGG16-based approach	92.15%
Hedhoud et al. [9]	2023	Pneumonia chest X-ray dataset	CNN-XGBoost	87.00%
This study	2026	Pediatric chest X-ray dataset	**DenseNet169**	**93.70%**

Figure 2 presents the ROC curves obtained from the stored test predictions for all three DenseNet models.

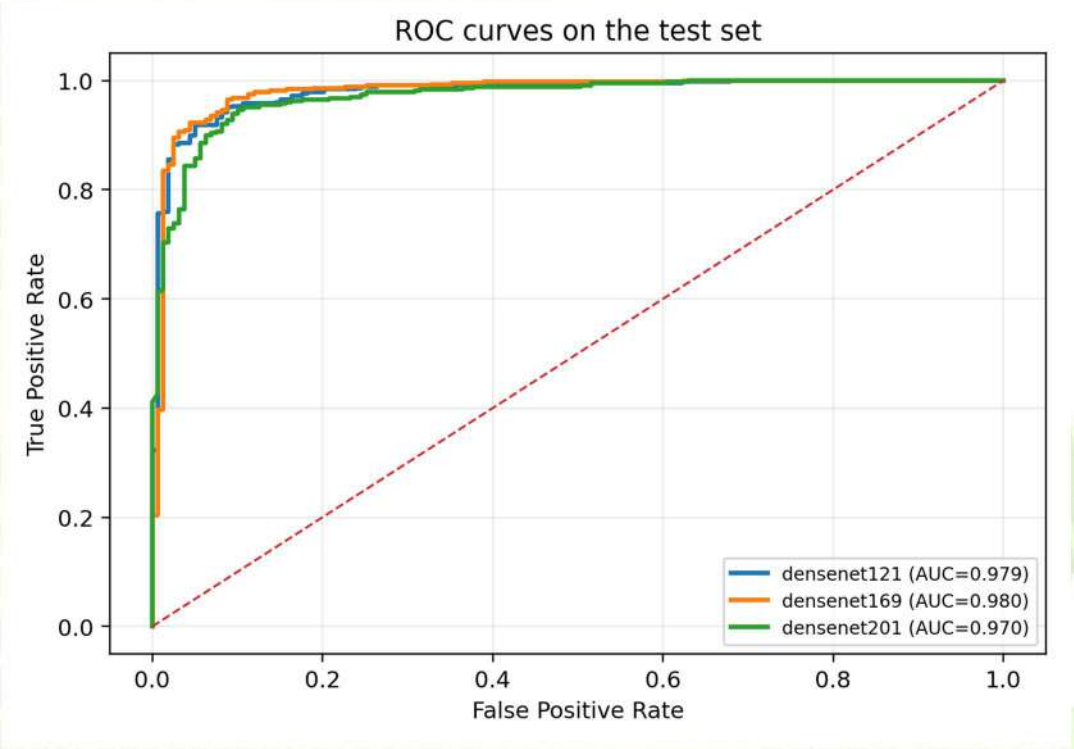


Figure 2. ROC curves obtained from the stored test predictions for all three DenseNet models.

The ROC curves confirm the strong ranking ability of all three models. Although the AUC values are close, DenseNet169 reaches the highest area under the curve (0.9796), followed by DenseNet121 (0.9785), while DenseNet201 remains lower at 0.9703. This pattern shows that increasing depth beyond DenseNet169 did not translate into better ranking performance under the current data and training regime.

Figure 3 shows the confusion matrices for DenseNet121, DenseNet169, and DenseNet201 on the held-out test set.

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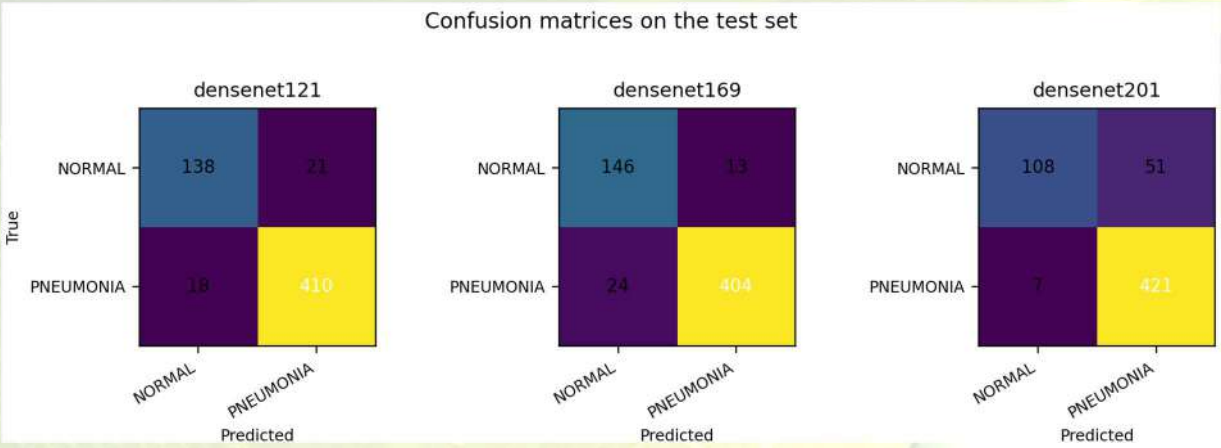


Figure 3. Confusion matrices for DenseNet121, DenseNet169, and DenseNet201 on the held-out test set.

The confusion matrices provide a more clinically interpretable view of the trade-off. DenseNet121 produced 21 false positives and 18 false negatives. DenseNet169 reduced false positives to 13, which improved specificity to 91.82%, but its false negatives increased to 24. DenseNet201 sharply reduced false negatives to 7 and therefore achieved the highest sensitivity (98.36%), yet it misclassified 51 normal images as pneumonia, dropping specificity to 67.92%. Consequently, DenseNet201 may be suitable only in settings where maximizing case capture is more important than avoiding unnecessary alarms.

Figure 4 compares the principal evaluation metrics across the three DenseNet variants.

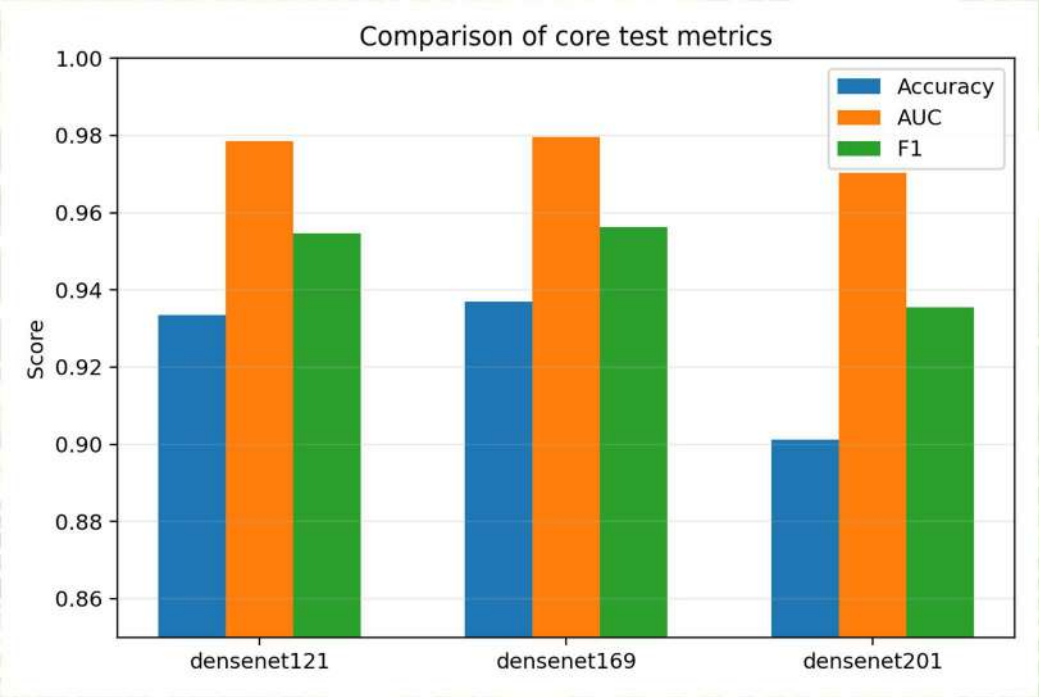


Figure 4. Comparison of the main test metrics across the three DenseNet variants.

4.1 Interpretation of model behavior

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The results indicate that the relationship between model depth and performance is not monotonic. DenseNet169 outperformed the other models on the most important overall evaluation measures. This suggests that, for the current data volume and split, DenseNet169 may provide the best compromise between representational richness and generalization. DenseNet121 remained attractive because its performance was extremely close to that of DenseNet169, which may make it a better candidate when inference cost or memory footprint matters. By contrast, DenseNet201 exhibited a stronger bias toward positive predictions, as reflected by its very high sensitivity and comparatively low specificity.

5. DISCUSSION.

Several strengths can be identified in the present experimental design. First, all three models were evaluated under the same input size, augmentation strategy, optimization framework, learning-rate schedule, and stopping rule, which makes the comparison internally fair. Second, the use of validation AUC for model selection and early termination is more appropriate than plain accuracy in class-imbalanced binary tasks. Third, the preservation of full prediction scores enables more detailed post hoc analyses, including ROC reconstruction and threshold-sensitivity assessment.

At the same time, several limitations should be clearly acknowledged. The present study does not include patient-level metadata, demographic information, acquisition-center information, or external validation sets. Therefore, the present paper cannot assess cross-institution generalization, demographic bias, or leakage risk. In addition, the present study does not include training curves, calibration metrics, confidence intervals, repeated-seed statistics, or statistical significance tests between models.

Another methodological limitation is the use of a fixed decision threshold of 0.5. Because DenseNet201 exhibits very high sensitivity with poor specificity, threshold optimization on the validation set could potentially produce a more balanced operating point. Likewise, cost-sensitive thresholding could align the system with different clinical priorities such as triage, screening, or confirmatory support.

An additional methodological point concerns the image-standardization procedure applied before feature extraction. The present study does not explicitly report whether any additional intensity normalization was applied beyond the stated preprocessing steps, and this point should therefore be clarified in future work. For clinically oriented deployment studies, calibration analysis, external validation, and explainability techniques such as saliency-based visual interpretation would further strengthen the evidential value of the system.

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6. CONCLUSION.

This paper presented a comparative study of three transfer-learning models for binary pneumonia classification from chest X-ray images under a unified experimental framework and preserved prediction-based evaluation protocol. All three DenseNet variants achieved test AUC values above 0.97, confirming the suitability of DenseNet-based transfer learning for this task. Nevertheless, DenseNet169 demonstrated the most balanced overall performance, with 93.70% accuracy, 0.9796 AUC, 96.88% precision, 94.39% sensitivity, and 91.82% specificity. DenseNet121 was nearly equivalent and may represent a practical lightweight alternative, whereas DenseNet201 favored sensitivity at the cost of excessive false positives. Future work should include repeated-seed experiments, threshold optimization, calibration analysis, and external validation before consideration for real-world clinical decision-support settings.

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