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A Mobile App for Enhancing Suture Skills through XAI

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ABSTRACT This study aims to enhance the suturing skills of medical practitioners by leveraging artificial intelligence (AI) techniques. Initially, a dataset of sutures was obtained from a hospital setting and underwent preprocessing to align with the model requirements. Subsequently, data augmentation was applied to enhance the dataset for improved performance. Using transfer learning, a classification algorithm was trained on the augmented dataset with %96.59 training and %79.24 validation accuracy. To ensure interpretability, SHAP (SHapley Additive exPlanations) analysis was employed to explain the decisions made by the classification algorithm, revealing the influential pixels in suture success. In the final stage, users were introduced to the project via a mobile application developed with Flutter and Dart. This app allows users to capture images of their sutures, which are then uploaded for analysis. The SHAP analysis results are presented visually to users, indicating which parts of the suture are deemed successful and which are not via heatmaps. By providing this feedback loop, the application aims to assist medical professionals in assessing and improving their suturing skills. This study presents a valuable tool for evaluating and enhancing medical suturing abilities, with potential implications for medical education and practice. In the future this preliminary study will be test with application users which will provide continuous feedback for model refinement.

KEYWORDS
Suture
Transfer learning
SHAP analysis
Mobile application
Medical education

INTRODUCTION

Mastering surgical skills is an essential component of medical training, crucial for aspiring clinicians as they progress towards professional competence. However, the path to acquiring these skills is filled with challenges. Traditionally, medical students have practiced suturing in hospital environments, using costly kits under the guidance of experienced professionals, either on real patients or animal models. This conventional approach, however, is marred by significant drawbacks. First of all, the financial implications of sourcing high-cost materials for suturing practice can place a considerable strain on students, particularly those navigating financial constraints.

The steep prices of suturing kits and related materials not only impose an economic burden but also threaten the inclusivity and fairness of surgical education. This may inadvertently prevent some students from acquiring critical surgical competencies (Solakoglu 2014). Furthermore, the logistical challenges of securing adequate time, space, and resources for hands-on suturing practice further complicate the learning process. The scarcity of ideal conditions for such practical training can severely limit students' opportunities to refine their suturing skills, thereby stunting their development in this essential aspect of medical practice (Haroon *et al.* 2020; Habuza *et al.* 2021). In contrast, the burgeoning field of AI is revolutionizing various facets of medicine, including educational methodologies. AI's integration into medical training, through innovative tools like surgical simulations and virtual patient scenarios, is paving the way for more effective skill acquisition. These technological advances offer a promising solution to the practical hurdles faced in traditional medical education, enabling a more efficient and engaging learning experience (Yang *et al.* 2021; Nguyen *et al.* 2021; Lekadir *et al.* 2021). Additionally, the widespread adoption of smartphones has facilitated the emergence of mobile applications equipped with AI technologies. These apps offer medical students the flexibility to practice and enhance their suturing skills anytime and anywhere, significantly expanding the avenues for practice and learning (Chakraborty *et al.* 2022; Gupta *et al.* 2022).

This study is driven by the ambition to make suturing education more accessible and impactful for medical students by leveraging the potential of AI and mobile technology. By bypassing the limitations inherent in conventional training methods, our proposed approach seeks to democratize the learning process, making it more cost-effective, flexible and conducive to skill development. Through this innovative lens, our aim is to enrich the educational landscape for medical students, ensuring they can acquire and refine their suturing skills with greater ease and efficiency (Zhang *et al.* 2023; Prentzas *et al.* 2023; Erdal *et al.* 2023).

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This study introduces a novel approach that combines Explainable AI (XAI) and mobile technology to provide an accessible, scalable, and interpretable suturing training platform. Unlike previous solutions, this study integrates SHAP analysis to enhance transparency, allowing users to understand AI decision-making processes in real-time.

The structure of this paper is organized as follows: Section offers a comprehensive background on XAI and application in health, introducing key principles and technologies that underpin our approach. In Section , the research methodology, which uses the capabilities of XAI to improve suture education, is given. Sections and **??** present and discuss the results of XAI, respectively. Finally, Section concludes the paper by summarizing the key findings and identifying avenues for future work, suggesting directions for further research and development in this promising field.

RELATED WORKS

This section provides an overview of the research landscape, starting with the broad applications and challenges of XAI, with a particular emphasis on its pivotal role in healthcare and medicine. This is followed by an overview of AI-based suture training.

XAI in Medicine

In the era marked by rapid advancements in open-source technologies, industries, including healthcare, are navigating the integration of AI into their practices. Academic research plays a pivotal role in this integration, pushing the boundaries of AI applications and fostering its adoption across various sectors, including the critical field of medicine (Haroon *et al.* 2020).

The development of AI solutions for medical decision support has been extensively reviewed by Prentzas *et al.* (2023), who emphasize the need for collaboration between medical and AI experts to design frameworks that improve the design, implementation, and evaluation of XAI. Erdal *et al.* (2023) emphasize the importance of interoperability and collaboration for adopting AI algorithms in healthcare. The healthcare sector, a primary beneficiary of these advancements, has witnessed transformative changes in service delivery, partly due to the integration of AI into medical practices. This integration has sparked interest in XAI, aiming to make AI's decision-making processes more transparent, especially in diagnostic applications (Habuza *et al.* 2021).

Significant contributions to improving the explainability of AI in medicine include studies on multimodal and multicenter data fusion techniques, as well as innovative uses of AI in combating the COVID-19 pandemic (Yang *et al.* 2021; Nguyen *et al.* 2021). AI integration into medical education has advanced significantly, especially in enhancing surgical skills. This study introduces a novel approach that combines XAI and mobile technology to provide an accessible, scalable, and interpretable suturing training platform. Unlike previous solutions, this study integrates SHAP analysis to enhance transparency, allowing users to understand AI decision-making processes in real-time ement of surgical skills. Duamwan and Bird (2023) highlight that simulation-based approaches in surgical training can be made more accessible and customized to individual needs through AI-driven models.

XAI systems, in particular, enable healthcare professionals to better understand the decision-making processes of AI algorithms, thus fostering greater trust and transparency in training. Luitse and his team illustrate that XAI, applied to cancer detection and the early diagnosis of Alzheimer's disease, visualizes the decisions made by AI models, thereby offering healthcare professionals more interpretable and reliable predictions. These techniques are also relevant to surgical training, where the interpretability of AI systems plays a significant role in advancing surgical skills.(Luitse *et al.* 2024)

The significance of AI-based imaging and analysis tools in medical education is increasingly recognized, as these tools shorten the learning curve and offer more personalized training experiences. Duamwan and Bird (2023) highlight that XAI techniques are critical not only in education but also in patient safety and treatment planning. Similarly, Luitse *et al.* (2024) demonstrate that AI approaches integrated with XAI can continuously monitor student performance in surgical training, develop individualized learning plans, and provide real-time, interpretable feedback.

AI-Based Suture Applications

The exploration of AI's potential has led to the development of technologies aimed at improving surgical training. Earlier studies by Dubrowski *et al.* (2005); Dosis *et al.* (2005) laid the groundwork for these advancements by focusing on the quantification of forces and movements during suturing and developing a dexterity-based motion analyzer, respectively. Kil *et al.* (2017) developed a computer vision algorithm to assess suturing ability, leveraging a synthetic deep-formed platform to evaluate critical metrics related to suturing skills. Following this, Choi and Ahn (2019) introduced a flexible sensor for suture training, embedded in an artificial skin simulator to enhance the sensory training aspect of surgical skills.

Further advancements include the study by Handelman *et al.* (2020), which combined computer vision-based software with fiber optic strain sensors to evaluate suture performance in surgery. While, Mansour *et al.* (2023) has developed a computer based suture training system which employs deep learning algorithms for suture training application. This study aims to build upon these advancements by evaluating and explaining suture images with XAI. In the field of surgical simulation training, the development of AI-powered systems has rapidly advanced. However, there remains a limited number of fully automated systems utilizing Explainable AI (XAI) for the evaluation of suturing skills and surgical techniques. Existing studies primarily focus on tracking forceps movements or rely on manual video-based assessment systems (Nagaraj *et al.* 2023). AI-based solutions have made it possible to provide real-time feedback and objective evaluations during training sessions (Fukuta *et al.* 2024). Nevertheless, there is a noticeable gap in the application of XAI for the comprehensive assessment of critical skills like suturing. Thus, the incorporation of both a mobile system and XAI in our study represents a significant innovation in this area.

Previous studies in this field have predominantly focused on simulation-based systems or tracking forceps movements for surgical training and assessment, yet a fully automated system specifically for suture training has not been developed. While these works have significantly contributed to the improvement and objective evaluation of surgical skills, the absence of studies utilizing explainable artificial intelligence (XAI) in this area highlights a clear gap in the literature. Consequently, although a direct performance comparison is not feasible, our research distinguishes itself by incorporating both mobile system usage and the relatively novel approach of XAI. This combination not only enhances the usability of surgical training but also provides deeper analytical insights, setting our work apart from previous studies.

MATERIALS AND METHODS

In this section, we outline the methodology followed in our study aimed at enhancing medical suture skills through AI and mobile technology. The approach involved several key components, including dataset acquisition, data augmentation techniques, VGG-16 transfer learning for model training, explanation of model decisions using SHAP analysis, and the development of a mobile application environment for user interaction.

Dataset

The dataset for suture training included real images of sutures, representing different types and quality levels. Each image contained different suture examples and sutures made under various conditions. When constructing the dataset, we considered factors such as different suturing materials, thread types, and suturing techniques. This allowed our model to recognize and classify a wide range of sutures. Training subset of the dataset consists of both successful and unsuccessful suture images. This inclusion enabled our model to learn from examples of both successful and unsuccessful sutures, facilitating a more comprehensive understanding of suture quality. Furthermore, the dataset was balanced via including a sufficient number of examples representing each suture type, thereby enhancing the model's ability to accurately classify different suture characteristics. The dataset consists of 2,000 images that encompass both successful and unsuccessful suture examples, offering a robust foundation for model training and evaluation. This extensive dataset significantly enhances the model's capability to accurately differentiate between various suture characteristics. Figure 1 presents illustrative examples of both successful and unsuccessful sutures

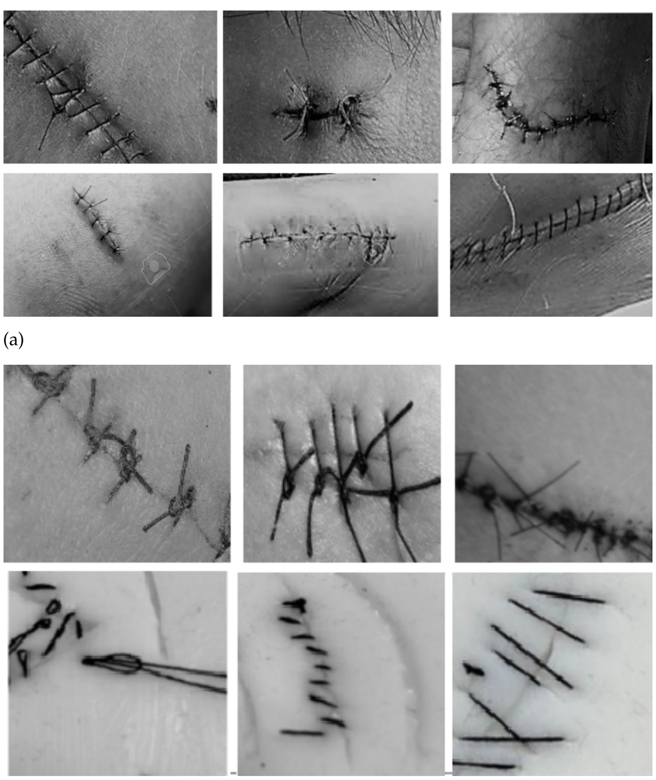


Figure 1 Suture examples from dataset a) Successful suture examples b) Unsuccessful suture examples

Data Augmentation

Data augmentation plays a crucial role in enhancing the robustness and generalization ability of our suture classification model. By applying various augmentation techniques to our dataset, we effectively increased its size and diversity, providing our model with a broader and more representative training example set. Techniques such as rotation, flipping, scaling, and shifting were utilized to simulate real-world variations and perspectives in suturing conditions. Additionally, random noise and distortions were introduced to images to mimic common flaws encountered in suturing tasks. This augmentation process not only expanded the dataset but also exposed the model to a wider range of suturing scenarios, thereby reducing overfitting issues. As a result, the model became more proficient in recognizing and classifying sutures under different conditions, ultimately enhancing its performance on unseen data. A series of images demonstrating these augmentation techniques is shown in Figure 2.

Figure 2 Data augmentation techniques implemented

Model Training

To train the suture classification model,transfer learning was employed using the VGG-16 architecture, a pre-trained convolutional neural network (CNN) widely recognized for its effectiveness in image classification tasks. Leveraging the features learned by VGG-16 on a large data set such as ImageNet, the model is adapted to our specific task of suture classification by fine-tuning its parameters on our augmented data set.

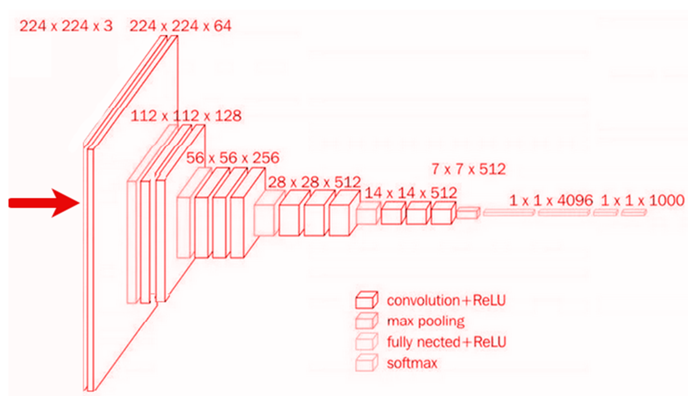


Figure 3 VGG-16 Structure

The convolutional base layers were freezed and only training the fully connected layers, the ability to capture high-level features was retained relevant to suturing patterns while minimizing the risk of overfitting, particularly given the relatively limited size of the dataset. This approach allowed us to exploit the generalization capabilities of VGG-16 while tailoring the model to our specific domain, resulting in improved performance and speed of convergence during training.

Model Explanation

To augment the transparency of VGG-16 model and provide clinically meaningful interpretations, SHapley Additive exPlanations (SHAP) has been employed as an interpretability tool. The Shapley value ϕ_i of a feature (i) is calculated as:

$$\phi_i(f) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|! \cdot (|N| - |S| - 1)!}{|N|!} [f(S \cup \{i\}) - f(S)] \qquad (1)$$

here $f(S)$ is the prediction of the model for feature subset S, and N is the set of all features.

SHAP offers a robust and intuitive framework for explaining model predictions by quantifying the contribution of each input feature to the final output. Shapley values for each pixel were computed in the input image, which generates visualizations that highlight the significance of individual pixels in the model's decision-making process. This facilitated a deeper understanding of which regions of the image played pivotal roles in the classification process, enabling us to pinpoint areas of focus and potential biases. In Figure 4, a heatmap visualization were presented depicting the results of our SHAP analysis, providing valuable insights into the factors driving our model's predictions and enhancing transparency and interpretability.

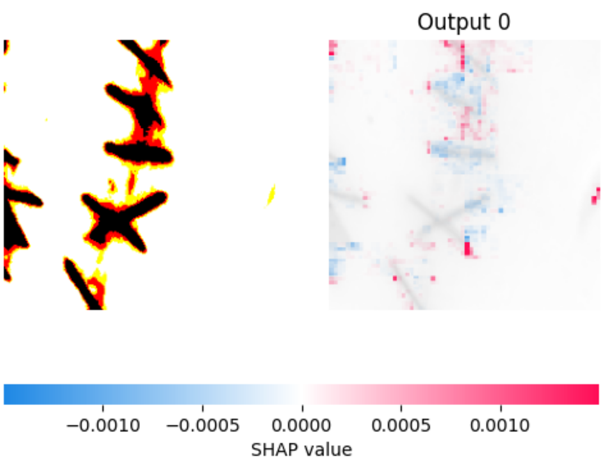


Figure 4 Explaining the image classificiation

Mobile App Development

In the development of our mobile application, Flutter has been employed for its efficiency and versatility in creating high-quality interfaces for both Android and iOS. The framework's rich widget library and hot reload feature greatly facilitated rapid prototyping and iterative development, allowing us to seamlessly refine user experience. Leveraging Dart, with its modern syntax, we implemented application logic and interface components that ensured a smooth and responsive user experience across various devices. Firebase played a crucial role as the app's backbone, offering a scalable and reliable infrastructure for functionalities like real-time data sync, user authentication, and cloud storage. Utilizing Firebase's Firestore database enabled efficient storage and retrieval of suture classification data, integrating seamlessly with our app and ensuring secure user authentication for personalized data access.

Our mobile application provides users the ability to capture and upload images of their suturees, receive instant feedback on classification results, and thus make informed decisions to improve their suturing skills. This capability fosters a dynamic community of enthusiasts, supported by an interface that emphasizes intuitive design, sleek navigation, and interactive features. The app's design focuses on usability and visual clarity, allowing users to easily navigate its features and access needed information.

It has been committed to continuous improvement based on user feedback, aiming to create an app that not only fulfills functional requirements but also appeals aesthetically and is user-friendly. The successful integration of Flutter and Firebase highlights the potential of these technologies to advance medical education and practice. Our application stands as a testament to the effectiveness of these tools in providing a practical, efficient, and engaging platform for medical practitioners to enhance their suturing skills.

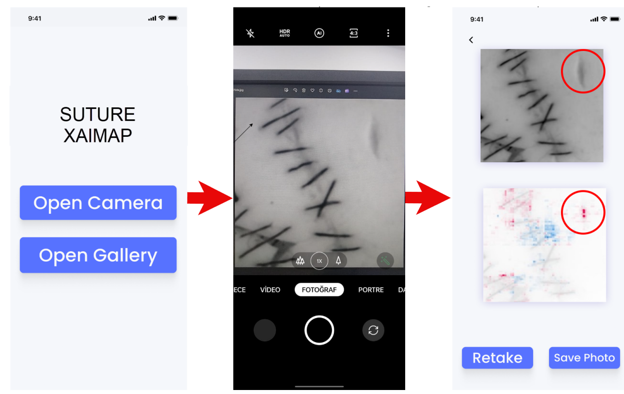


Figure 5 UI the Mobile App

RESULTS AND DISCUSSION

In this section, the results of training the transfer learning model for the surgical suturing task. An overview of the model's performance metrics is given in Table 1, followed by a detailed analysis of the results.

Table 1 Hyperparameters for Transfer Learning

Parameter	Value
Base Model	VGG-16
Optimizer	Adam
Loss Function	Binary Crossentropy
Learning Rate	Default (0.001)
Batch Size	32
Epochs	10
Final Training Accuracy	96.59%
Validation Accuracy	79.24%

The transfer learning model was trained using the VGG-16 architecture with hyperparameters specified in Table 1. The training process resulted in a final training accuracy of 96.59.

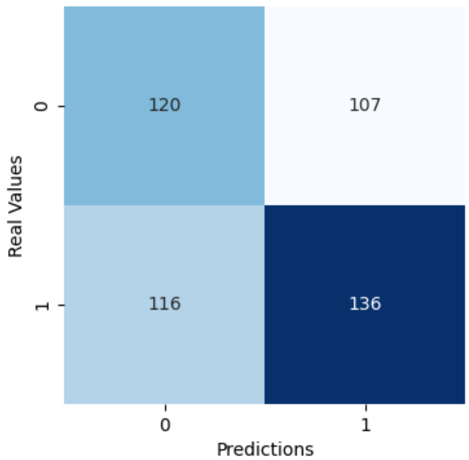
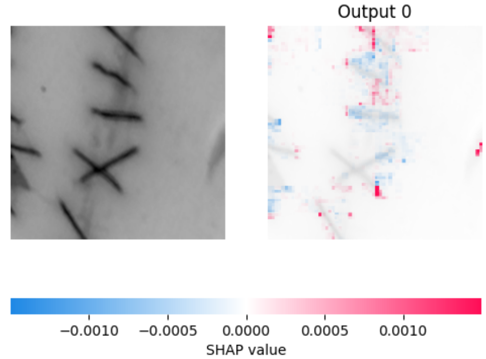


Figure 6 Confusion matrix

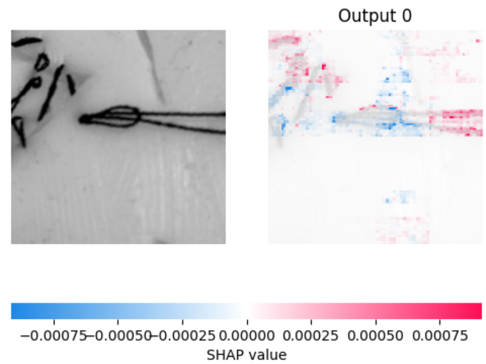
In classification tasks such as surgical suture image classification, the confusion matrix plays a crucial role in evaluating the performance of the model. It provides a detailed breakdown of the model's predictions compared to the ground truth labels, allowing us to identify any patterns of misclassification. Specifically, the confusion matrix displays the true positive (TP), true negative (TN), false positive (FP), and false negative (FN) predictions. From this information, key metrics such as precision, recall, and F1-score can be calculated, providing insights into the model's ability to correctly classify different classes. Analyzing the confusion matrix allows us to identify areas where the model struggles, enabling targeted improvements to boost overall performance. Additionally, in Figure 6, the confusion matrix of the trained model is presented in its final state, providing a visual representation of the model's performance across different classes with heatmaps as shown in Figure 7.

The implications of this study are profound, extending the application of AI-driven feedback to enhance suture skills and democratize medical education (Mansour *et al.* 2023). Similarly to the advancements discussed by Kil *et al.* (2017); Choi and Ahn (2019); Handelman *et al.* (2020), this study leverages AI to make advanced training tools more accessible, echoing the need for collaboration highlighted by Prentzas *et al.* (2023); Erdal *et al.* (2023). The adoption of SHAP analysis to interpret AI decisions mirrors the movement of the broader healthcare sector toward transparent and trustworthy AI systems, underscoring the importance of explainability in AI, as advocated by Habuza *et al.* (2021) and the collaborative frameworks suggested by Prentzas *et al.* (2023). Furthermore, this study's emphasis on interdisciplinary collaboration aligns with the innovative solutions seen in the works of Dubrowski *et al.* (2005); Dosis *et al.* (2005), where technical and medical expertise converge to enhance surgical training. In the future, the integration of AI-driven feedback systems with medical training simulations could parallel the exploratory efforts in multimodal AI techniques discussed by Gupta *et al.* (2022) and the development of comprehensive tools such as those by Dosis *et al.* (2005), pushing the boundaries of surgical skill training.

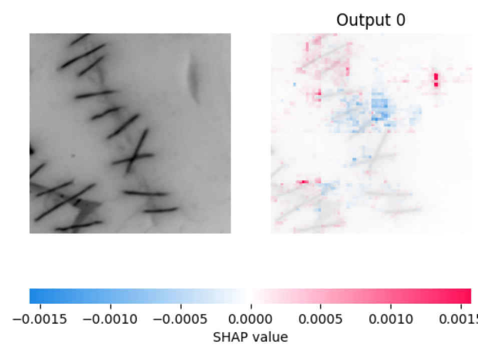
This study's approach exemplifies a promising step towards leveraging AI not only to enhance specific medical skills but also to improve the accessibility and quality of medical education, resonating with the goals outlined by Chakraborty *et al.* (2022); Zhang *et al.* (2023) to use technology to advance healthcare outcomes. The find-



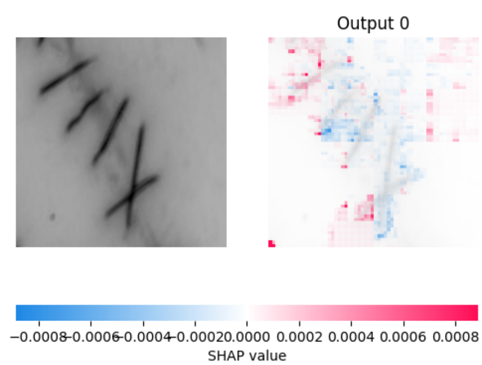
(a)



(b)



(c)



(d)

Figure 7 Explaining examples of (a) True Positive, (b)True Negative, (c) False Positive and (d) False Negative Results ings of this study are in line with those discussed by Dubrowski *et al.* (2005), who emphasized the importance of various criteria for skill assessment. Similarly, our study highlights the limitations of AI models in generalizing across different suture techniques. Expanding the dataset to include a wider range of procedures would improve the generalization capabilities of the model, just as strength-based metrics provide comprehensive assessment in various surgical contexts (Trejos *et al.* 2014).

The conclusions of this study align with the findings of Choi and Ahn (2019), which emphasize the importance of adapting medical training tools to varying hardware capabilities. Much like how Choi and Ahn (2019) highlighted the need for flexible solutions in diverse training environments, we recognize that the accuracy of suture classification may vary depending on mobile device specifications, such as camera quality and processing power. In response, our future work will focus on implementing advanced image processing techniques and adaptive algorithms to ensure consistent model performance across a range of devices, thus enhancing the accessibility and reliability of the application in diverse medical contexts. The development and deployment of our mobile application provide a cost-effective alternative to traditional suture training methods, which typically require professional surgeons to evaluate suture quality. Utilizing XAI on our server, the application eliminates the need for such costly assessments. This aligns with findings by Jiang *et al.* (2019), who demonstrate that mobile health apps can significantly reduce costs and enhance efficiency compared to conventional methods. Our approach thus offers a financially advantageous and effective solution for suture training.

CONCLUSION

The results demonstrate a promising step toward the refinement of medical education, particularly in suture practice. By achieving a high training accuracy and a respectable validation accuracy, the model underscores the viability of using transfer learning to tailor preexisting, robust neural network architectures to specific medical tasks. SHAP analysis further enhances this approach by providing interpretable insights into model predictions, thereby demystifying the AI's decision-making process and fostering trust among users. The mobile application, developed using Flutter and Firebase, offers a user-friendly platform that bridges the gap between sophisticated AI models and end-users, namely medical students and professionals seeking to refine their suturing skills. The ability of the app to provide instant feedback on suturing technique represents a significant leap towards accessible, personalized medical education.

In future work, the reach and efficacy of this innovative educational tool will be improved by enriching the data set with a wider variety of suture types and conditions that could further improve the robustness and accuracy of the model. Incorporating user-generated data from the mobile app could provide a continuous feedback loop for model refinement. The next phase of this project will involve deploying the mobile application in clinical training environments to assess its impact on real-world medical education. This phase will evaluate the application's usability and its potential to enhance clinical skills training. Future iterations will include empirical testing with medical students and healthcare professionals, collecting detailed feedback on the application's effectiveness in real-world settings. Incorporating this feedback will allow us to refine the application's functionality and ensure it meets the practical needs of medical practitioners.

In the long term, AI-enhanced suture training holds the potential to improve not only medical education but also patient outcomes by providing more accessible and consistent training.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this document.

Data availability

The data that support the findings of this study are not openly available due to reasons of data set availability and are available from the corresponding author upon reasonable request.

Ethical consideration

Data privacy and the potential for bias in AI models are critical ethical considerations in the deployment of AI-based medical training tools. In this study, we prioritize these concerns by ensuring that all user data is anonymized and securely stored in compliance with stringent data protection standards. Additionally, we are committed to addressing and mitigating potential biases that may arise from imbalanced datasets. This involves implementing rigorous methodologies for data collection and preprocessing to ensure fairness and representativeness. This process aims to preserve the integrity and reliability of the AI model in medical training applications.

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