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# Can artificial intelligence algorithms recognize knee arthroplasty implants from X-ray radiographs?

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## ABSTRACT

**Aims**: This study aimed to investigate the use of a convolutional neural network (CNN) deep learning approach to accurately identify total knee arthroplasty (TKA) implants from X-ray radiographs.

**Methods**: This retrospective study employed a deep learning CNN system to analyze pre-revision and post-operative knee X-rays from TKA patients. We excluded cases involving unicondylar and revision knee replacements, as well as low-quality or unavailable X-ray images and those with other implants. Ten cruciate-retaining TKA replacement models were assessed from various manufacturers. The training set comprised 69% of the data, with the remaining 31% in the test set, augmented due to limited images. Evaluation metrics included accuracy and F1 score, and we developed the software in Python using the TensorFlow library for the CNN method. A computer scientist with AI expertise managed data processing and testing, calculating specificity, sensitivity, and accuracy to assess CNN performance.

**Results**: In this study, a total of 282 AP and lateral X-rays from 141 patients were examined, encompassing 10 distinct knee prosthesis models from various manufacturers, each with varying X-ray counts. The CNN technique exhibited flawless accuracy, achieving a 100% identification rate for both the manufacturer and model of TKA across all 10 different models. Furthermore, the CNN method demonstrated exceptional specificity and sensitivity, consistently reaching 100% for each individual implant model.

**Conclusion**: This study underscores the impressive capacity of deep learning AI algorithms to precisely identify knee arthroplasty implants from X-ray radiographs. It highlights AI's ability to detect subtle changes imperceptible to humans, execute precise computations, and handle extensive data. The accurate recognition of knee replacement implants using AI algorithms prior to revision surgeries promises to enhance procedure efficiency and outcomes.

**Keywords**: Artroplasty, implant, artificial intelligence, detection

## INTRODUCTION

Total knee arthroplasty (TKA) is a highly effective surgical technique for severe knee osteoarthritis, and it is estimated that there will be more than 1.26 million cases per year in the United States alone.[1] However, for some individuals, surgery ends in failure or poor outcomes, requiring revision surgery. As the population of arthroplasty patients continues to grow, so does the volume of patients requiring revision.[2,3] When revision is required, identification of the implant manufacturer and model can be an important step in addressing complications and failures after arthroplasty of the knee. Implants are not recognized preoperatively in patients needing reoperation because of irregularities in the reporting of implant information and difficulties in accessing these records, especially from out-of-hospital systems. As a result, patients wait longer for treatment, are sent to referral facilities more often than required, experience higher rates of perioperative morbidity, and pay more for their medical care. Millions of dollars are wasted annually on identifying arthroplasty implants before revision surgery.[4] In an investigation of arthroplasty surgeons, 88% of the people who participated indicated that implant identification was crucial prior to revision arthroplasty surgery.[5] When patients apply to several facilities, it is not always possible to view their application records. Moreover, it might be challenging to acquire data

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regarding the initial procedure since the switch from paper to electronic recording methods is still relatively recent.

Successful visual processing and automated identification methods using deep learning, a branch of artificial intelligence (AI), have been created, most notably for detecting papilledema from ocular fundus photos. Visual recognition with convolutional neural network (CNN) deep learning algorithms is becoming increasingly popular in many fields, including orthopedics and traumatology.[6-8] Given the challenges of identifying implants among a substantial number of potential manufacturer models, a CNN deep learning algorithm could serve as a promising method to facilitate the instantaneous identification of knee arthroplasty implants, considering the complexities associated with their characterization.

This study aimed to investigate the use of a CNN deep learning approach to accurately identify knee arthroplasty implants from X-ray radiographs. This could improve the efficiency and outcomes of revision surgeries.

## METHODS

This retrospective study was carried out with the permission of the Fırat University Non-interventional Researches Ethics Committee (Date: 29.12.2022, Decision No: 16-21). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Using post-operative and pre-revision AP and lateral radiographs of TKA patients, we trained, validated, and tested a CNN deep learning system. AP and lateral knee X-rays of at least 10 patients with the same model and knee prosthesis implantation were examined. Unicondylar knee replacements and revision knee replacement models were excluded from the analysis. Patients whose AP and lateral X-ray images were either unavailable or of low quality were also excluded from the study. The assessment of X-ray quality was conducted by two orthopaedic surgeons who possess experience in arthroplasty. In addition, participants with other implants (plate screws, etc.) in their X-rays were excluded from analysis. The authors of the study assessed the highest possible quantity of knee arthroplasty implant manufacturers and models, taking into account the availability of accurate and reliable information at the respective healthcare facilities. As a result the following 10 different models and manufacturers of TKA replacements were tested: Stryker (Scorpio), Smith and Nephew (Genesis II), Implantcast (ACS), Biomed (Vanguard), Zimmer (NexGen), Hipokrat (2000 CR), Tıpsan (T08), Zimed (V17), Tıpmed (TPM-8), and Neologic (Fortuna). Only cruciate-retaining models of knee arthroplasty implants were evaluated. The main operation operative note was used to identify the implant type, which was then cross-checked with the implant serial number. 69% of the data was used for the training set and the remaining 31% for the test set. To address the limited number of images, we applied image augmentation techniques. Additionally, given the small dataset, we leveraged transfer learning and fine-tuning methods to enhance our model's performance. Fine-tuning was carried out using the images in the training set, and both sets were randomly selected from the complete dataset. For evaluating the classification performance, we employed at least two key metrics: accuracy and F1 score. While accuracy was applied to balanced datasets, the F1 score was used to assess classification performance in situations of data imbalance. Our software development and performance assessments were conducted using the Python programming language, with the implementation of our method facilitated by the TensorFlow library (**Figure 1**). The data processing and testing were expertly overseen by a computer scientist with a specialization in artificial intelligence. We determined accuracy by comparing the predicted implant stem design with the highest degree of confidence to the actual implant design, while also calculating the specificity and sensitivity of our method to provide a comprehensive evaluation of its performance.

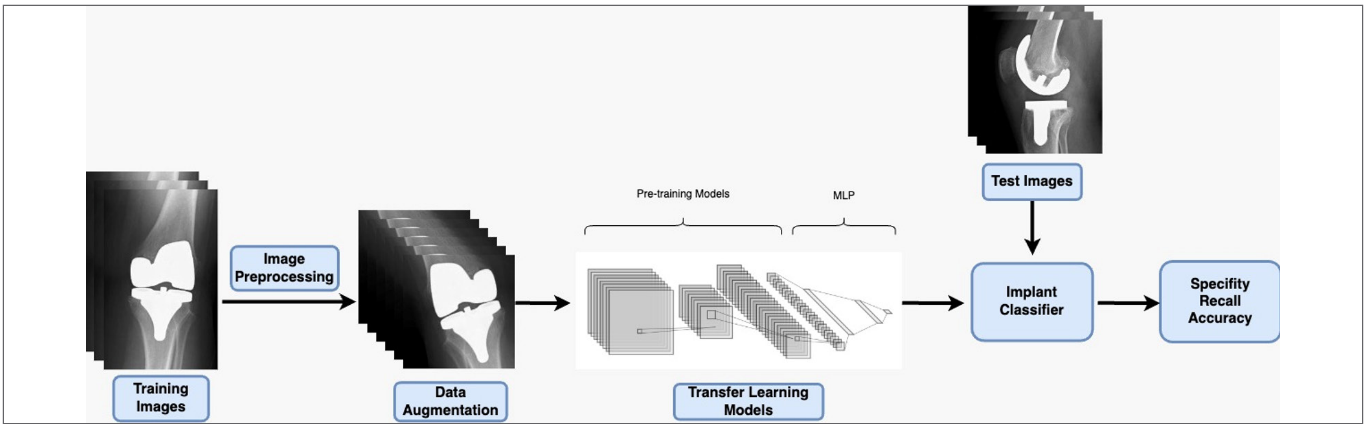


**Figure 1.** Flowchart of the algorithm model training, left to right: the input images are fed to the convolutional neural network after preprocessing and augmentation (increasing the number of images used for training). Once training is complete, the model is checked against a separate validation set to ensure its accuracy.

## RESULTS

In total, 282 AP and lateral X-rays from 141 patients were evaluated. 10 different manufacturers' knee prosthesis models were included with different numbers of X-rays (**Figure 2**). The CNN method demonstrated an identification accuracy of 100% for each individual model in identifying the manufacturer and model of TKA among 10 different models. The specificity and sensitivity of the CNN method were 100% for each implant model separately (**Table 1**).

## DISCUSSION

The most important finding of this study is that the deep learning CNN method showed a remarkable identification accuracy of 100% in identifying the manufacturer and model of TKA implants among different models when evaluating AP and lateral X-ray images. Moreover, the CNN method exhibited an extraordinary level of specificity and sensitivity, both set at 100%, for each individual implant model, further underscoring its robustness and reliability in discerning nuanced characteristics among distinct prosthesis brands. Considering that recognizing knee replacement implants prior to revision knee replacement surgeries significantly affects the effectiveness and outcomes of revision surgeries, an AI algorithm that instantly and accurately recognizes knee arthroplasty implants is likely to provide significant benefits.[5,9]

In a prior study related to deep learning CNN method, an evaluation was conducted on nine different manufacturers and models of knee prostheses. The trained AI algorithm achieved an impressive 98.3% success rate. They also found a sensitivity of 94.6% and a specificity of 99.4%.[10] It's important to note that this study exclusively focused on

**Figure 2.** Knee X-rays from ten different manufacturers. From left to right: Tıpsan AP and lateral X-rays, Zimed AP and lateral X-rays, Zimmer Ap and lateral X-rays, Smith and Nephew Ap and lateral X-rays, Stryker AP and lateral X-rays, Neologic AP and lateral X-rays, Biomed AP and lateral X-rays, Hipokrat AP and lateral X-rays, Tıpmed AP and lateral X-

**Table 1.** Deep learning performans for detection of each knee arthroplasty implant's model and manufacturer

| Artroplasty implants | Training X-ray (n) | Testing X-ray (n) | Accuracy (%) | Sensitivity (%) | Specifity (%) |
|---|---|---|---|---|---|
| Stryker (Scorpio) | 14 | 6 | 100% | 100% | 100% |
| Smith and Nephew (Genesis II) | 16 | 8 | 100% | 100% | 100% |
| Implantcast (ACS) | 16 | 8 | 100% | 100% | 100% |
| Biomed (Vanguard) | 14 | 6 | 100% | 100% | 100% |
| Zimmer (NexGen) | 14 | 6 | 100% | 100% | 100% |
| Hipokrat (2000 CR) | 20 | 8 | 100% | 100% | 100% |
| Tıpsan (T08) | 24 | 12 | 100% | 100% | 100% |
| Zimed (V17) | 24 | 10 | 100% | 100% | 100% |
| Tıpmed (TPM-8) | 26 | 12 | 100% | 100% | 100% |
| Neologic (Fortuna) | 26 | 12 | 100% | 100% | 100% |

assessing AP X-rays. The scope of the prosthetic models under examination encompassed both unicondylar and revision knee prostheses. In contrast, our own study may have yielded a higher success rate due to its exclusive analysis of bidirectional radiographs. Furthermore, the inclusion of revision knee prostheses and unicondylar knee prostheses in the evaluation may have created deficiencies in the deep learning CNN method's detection technique, contributing to a lower overall success rate. In similar research, Paul et al.[11] found that AI could reliably discern the difference between two brands of knee prosthesis and discriminate between the presence or absence of knee prosthesis with 100% sensitivity and specificity. Although the scope of this study is smaller than our review, the success power of the CNN method is remarkable, similar to our study.

In recent years, there have been studies documenting the effective application of artificial intelligence in various aspects of arthroplasty and other orthopaedic topics.[12-14] The findings from these studies, including our own, demonstrate the potential success of artificial intelligence in image processing. Furthermore, AI's potential in medical image analysis extends across various domains. For instance, endotracheal tubes and central catheters' positions on X-ray images were successfully identified using the CNN approach in two different experiments.[15,16] The CNN method was also able to identify these medical devices, just like our research indicated they could. Our study adds to this growing body of evidence by demonstrating that the CNN method can identify medical devices like knee prostheses with a high degree of accuracy and precision.

Lakhani and Sundaram investigated the efficacy of a deep learning CNN in detecting features of tuberculosis on chest radiographs.[17] It was verified by a cardiothoracic radiologist that the deep learning CNN correctly detected 100% of cases. From the perspective of researchers, AI has demonstrated remarkable success in various domains, including medical image analysis, owing to several pivotal factors. AI algorithms, particularly those grounded in deep learning, excel at processing vast datasets and discerning intricate patterns within them, enabling the identification of subtle anomalies, variations, or features that may challenge human observers in the realm of medical image analysis.[18,19] Additionally, AI systems exhibit unwavering consistency in their performance, unaffected by factors such as fatigue, distraction, or emotional states, which can significantly impact human accuracy and reliability—especially crucial in medical diagnostics where errors can carry grave consequences.[20] Moreover, AI systems have significant memory capacity, allowing them to store and retrieve extensive knowledge, so they can continually improve their performance over time. This feature can be particularly advantageous in medical fields that rely on accumulated expertise. This success of AI in medical image analysis and healthcare is due to its computational power, pattern recognition ability, and capacity to exploit adaptability.[21-23] However, there are still hesitations to replace healthcare professionals, but rather to emphasize that AI serves as a valuable tool to enhance their ability to deliver superior patient care.

The findings of this study provide a foundation upon which to build more research into AI-assisted identification strategies for knee arthroplasty. Additionally, conducting a longitudinal study to assess the algorithm's performance on a larger and more diverse dataset, including various prosthesis models and manufacturers, would further validate its robustness and reliability in real-world clinical scenarios. As AI technologies continue to evolve, these endeavors will collectively contribute to refining and expanding the capabilities of AI-powered implant identification methods in the realm of knee arthroplasty. CNN may also be employed for more challenging tasks, such as the detection of postoperative problems (such as dislocations and osteolysis). Further progress can be made by increasing research in these areas.

### Limitations

One of the limitations of the current study is that the brands of a small number of knee prosthesis manufacturers were evaluated. It's possible that there are other brands and models of knee arthroplasty implants out there that we haven't come across. We cannot predict how the AI program will perform when it encounters more prosthesis brands. The second limitation of the study was the exclusion of posterior cruciate ligament-sacrificing knee prosthesis models. Due to the limited availability of data in our library, we were unable to analyse images of posterior cruciate ligament sacrificing knee arthroplasty implant models. Therefore, our evaluation was restricted to posterior cruciate ligament retainer models of knee arthroplasty implants. When these prosthesis models are included, it may perhaps reduce the detection power of the AI algorithm.

## CONCLUSION

This study demonstrates the remarkable potential of deep learning AI algorithms in accurately identifying knee arthroplasty implants from X-ray radiographs. Furthermore, the results of this study underline the enormous potential of artificial intelligence that can recognize subtle changes that may escape human observation, perform precise calculations, and store large amounts of information. Accurate recognition of knee replacement implants with AI algorithms prior to revision surgeries is likely to improve the efficiency and outcomes of such procedures. While there are some limitations to consider, such as the need for a wider range of prosthesis models and brands, the potential for advancing this technology is clear and promises even more significant contributions to patient care and outcomes.

## ETHICAL DECLARATIONS

**Ethics Committee Approval:** The study was carried out with the permission of the Fırat University Non-interventional Researches Ethics Committee (Date: 29.12.2022, Decision No: 16-21).

**Informed Consent:** Because the study was designed retrospectively, no written informed consent form was obtained from patients.

**Referee Evaluation Process:** Externally peer-reviewed.

**Conflict of Interest Statement:** The authors have no conflicts of interest to declare.

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