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Artificial intelligence assisted assessment of pre- and post-arthroplasty lower limb alignment on long-leg and knee close-up X-rays

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Abstract

In this study, we present and evaluate a suite of deep learning algorithms to assist orthopedic surgeons in the analysis of pre- and post-operative lower limb X-ray images. Deep learning algorithms obtained similar results as surgeons on the measurement of 10 different angles used for the assessment of the lower limb alignment.

1. Introduction

More than 2 million knee arthroplasties are realized every year worldwide, and this number is constantly growing [**1**]. The follow-up of lower limb implants is routinely performed through the analysis of X-ray images to evaluate the characteristics of the implanted prosthesis and the limb alignment. This task is time-consuming and remains challenging for non-specialized physicians and junior surgeons.

The progress of artificial intelligence, driven by neural networks, led to numerous applications in the medical field. A subclass of these networks, called Convolutional Neural Networks (CNN), obtained excellent results in analyzing medical images [**2**].

Concerning musculoskeletal imaging, artificial intelligence has been used mostly on two topics: fracture detection and knee osteoarthritis scoring [**3**,**4**]. However it could be expanded to many other applications [**5**].

In this study, we developed a suite of deep learning algorithms to assist orthopedic surgeons in the assessment of pre- and post-operative lower limb X-rays.

2. Materials and Methods

We collected data from the PACS of an orthopedic medical center: following the European regulatory framework, images were de-identified and never exported out of this medical center. The retrospective database contains 103,360 X-rays of 19,560 adult patients including both knee close-up and long-leg images.

The first step of our study consisted in cleaning our database to ensure its quality. We defined 8 processing steps, including removing images of bad quality and retaining only knee and long-leg X-rays in AP view. We performed manual annotations and trained one convolutional neural network (CNN) for each of these steps. Finally, we obtained two databases of 12,095 knee close-ups and 2,246 long-leg X-rays.

Secondly, we trained different neural networks to measure prosthesis positioning (i.e. angle between the prosthesis components and the bones' axes) and limb alignment from manually labeled anatomical landmarks. Therefore, we annotated landmarks on 2,717 and 1,000 images respectively.

The knee close-up images required two CNNs (one for the AP and one for the profile view) to predict the landmarks. The long-leg X-rays required a supplementary CNN to determine approximately the localizations of hip, knee and ankle. For each area we then optimized a network to produce precise landmarks.

To evaluate the impact of the assistance by our tool on the observer's reliability, we recruited three surgeons to measure the angles on a subset of 60 randomly selected images (half AP, half profile views) of the knee close-up database ("comparison subset").

The CNNs, adapted from the ResNet architecture, were implemented using the Python framework PyTorch. The database was split into training, validation and testing sets (70%, 10%, 20%). We seeked the best performances on the validation set, using for instance hyperparameters search and data augmentation techniques.

3. Results

On the quality control tasks, the neural networks obtained a mean Area Under the Curve (AUC) value of 0.98 (std 0.0236).

For the knee close-up, the algorithms' performance was assessed on prosthesis alignment by calculating the mean angle error. The algorithms obtained 1.71° (std 1.53°), close to the surgeons' mean difference of 1.69° (std 1.52°) on the comparison subset. An example of the algorithms' performance is shown on Figure 1.

For the long-leg images, we evaluated the measurement by calculating the mean error on the predicted angles. Our pipeline reached a mean angle error of 2.59° (std 3.94°). An example of the pipeline's performance is shown on Figure 2.

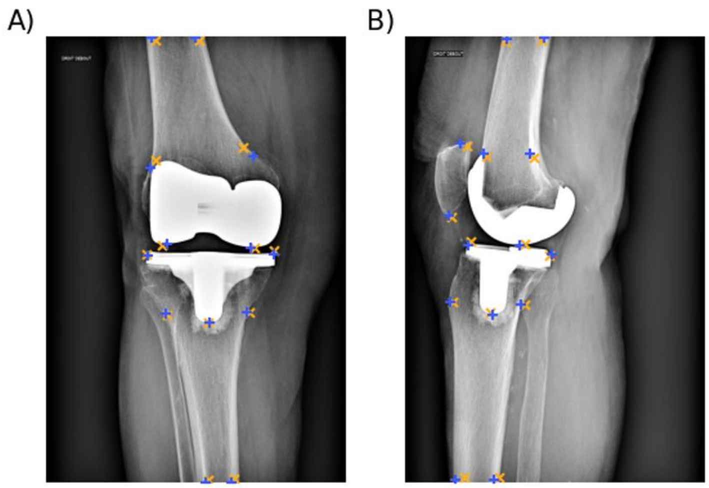

Figure 1 : Example knee close-up X-ray image with annotated (blue) and predicted (yellow) points in AP (A) and profile (B) views

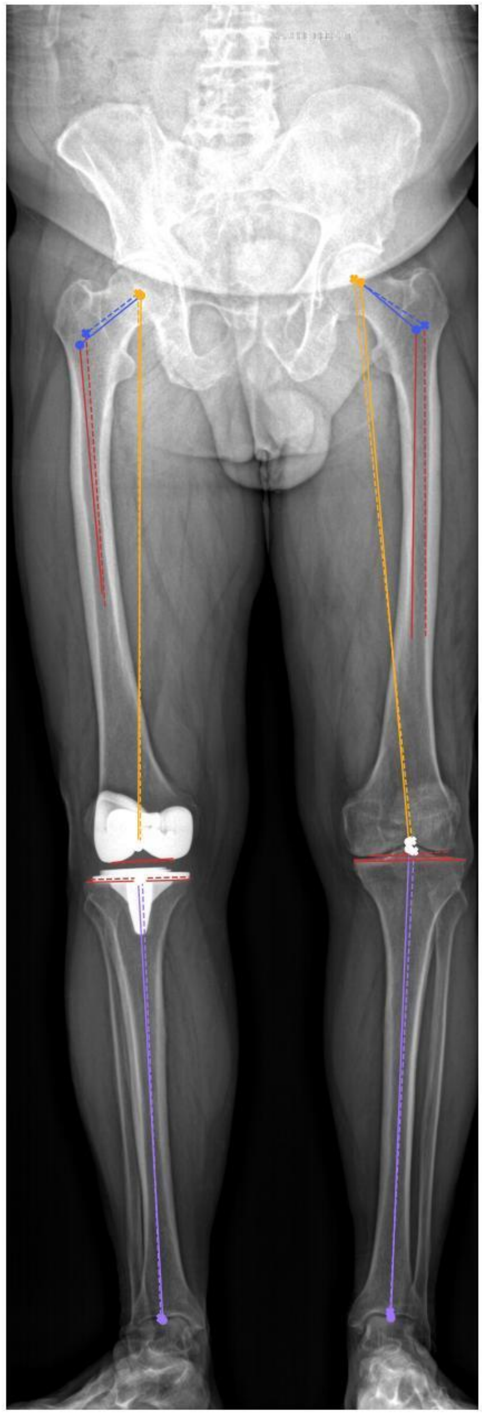

Figure 2:
Example long-leg X-ray image with annotated (continuous lines, circle points) and calculated points and lines (dashed lines, cross points).

4. Discussion and Conclusion

This work introduces a suite of deep learning algorithms to assist in the interpretation of pre- & post-operative knee close-up and long-leg X-rays. Our tool can automatically (1) perform quality control of X-rays to ensure their characteristics, (2) measure the prosthesis positioning on the knee close-up image and (3) determine the lower limb alignment angles on long-leg images.

Different studies showed that computer assistance increased the intra-observer agreement while speeding up the measurement process [**6**,**7**]. Others demonstrated a strong intra-observer reliability for various levels of expertise, while the inter-observer agreement is proportional to the observers' experience [**8**,**9**]. Our neural networks performed at the level of senior surgeons and thus could be used to assist them by standardizing and automatizing their measurements.

These promising results were achieved on a mono-centric dataset. To prove the robustness of our algorithms, we will perform, in a second step, a comparative study, using a large, multicentric and heterogeneous dataset.

This study shows that innovative technologies can be integrated into the orthopedic surgeon's routine. In particular artificial intelligence is well suited to assist in medical imaging analysis as it produces accurate and standardized measurements.

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