Deep learning to classify arteriovenous access aneurysms in hemodialysis patients

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Vascular access aneurysms are common in hemodialysis patients with arteriovenous (AV) fistulas and grafts. Reported incidences of aneurysms range from 5% to >60% [1]. While often without significant clinical sequelae, patients may experience complications such as an inability to dialyze owing to rupture risk and—in rare cases—rupture without warning and with potentially catastrophic, life- and limb-threatening consequences [1–4].

We developed a novel approach to monitoring of AV aneurysms that builds on the analysis of digital AV access images by a cloud-based deep learning system [5]. We used tablets to take digital images of AV accesses before cannulation in a large and diverse group of hemodialysis patients from 20 dialysis clinics across six US states. The images included the cannulation site and the adjacent skin. A white background was used to enhance contrast. Images were taken with standard resolution and at ambient light. Using a newly developed app, deidentified images were instantaneously uploaded to the cloud in compliance with the Health Insurance Portability and Accountability Act. Images were then adjudicated by a team of vascular experts. Based on characteristics such as size, skin hypopigmentation and presence or absence of skin ulcers, the vascular access experts classified aneurysms as ‘not advanced’ or ‘advanced’ (Figure 1). Adjudicated images were then randomized into training (70%) and validation (30%) sets. We standardized the images’ resolution to 1000 × 750 × 3 before presenting them to a deep learning convolutional neural network (CNN). Deep learning systems are already widely used in medical applications [6, 7]. The CNN was used in transfer learning mode and utilized the pre-trained Amazon SageMaker image classification algorithm, which we fine-tuned to AV access images. CNN classification performance was measured by the area under the receiver operating characteristics curve (AUROC) in the validation set.

We collected 1425 AV access images. A total of 84 photos (6%) were not adjudicated owing to external artifacts (e.g. bandages and wraps) or skin characteristics (e.g. tattoos and surgical scars). Of the remaining 1341 images, the adjudicators classified 1093 images (81.5%) as ‘not advanced’ and 248 (18.5%) as ‘advanced’ aneurysms. In the validation set, the classification by the CNN resulted in an AUROC of 0.96 (Figure 2). The CNN evaluates the images without considering the color of the skin. To better understand the impact of skin color on CNN performance, we categorized by visual inspection the skin tone of the 402 validation images as ‘dark’ (n = 211) or ‘light’ (n = 191). CNN performance did not materially differ by skin tone.

In summary, we present a point-of-care app and a cloud-based artificial intelligence tool to classify AV aneurysms automatically and accurately. The app captures and seamlessly transfers digital images of the AV access to the cloud, where they are then classified by a deep learning CNN. The classification is dispatched back to the healthcare provider in <1 sec. Real-world testing in a large and demographically diverse hemodialysis population demonstrated the feasibility and high accuracy.

Future research should explore the inclusion of clinical parameters (e.g. access recirculation, blood flow, previous access interventions, prolonged bleeding time, pain, pictures taken before and after arm raising) in the classification model. We also believe that the longitudinal incorporation of images into electronic health records will add value and provide healthcare providers with additional insights into the natural history of
FIGURE 1: Categories of AV access aneurysms. (A) AV access images from six patients with 'not advanced' AV aneurysms. (B) AV access images from six patients with 'advanced' AV aneurysms.

FIGURE 2: Diagnostic performance of the CNN. The figure shows the receiver operating characteristics curve. The area under the curve (AUC) for the validation data set (n = 402) is 0.96.

AV aneurysms. Quantitation of the app's clinical effectiveness warrants studies that assess if the expert clinical evaluation of aneurysms classified by the CNN as 'advanced' will reduce the rate of complications associated with aneurysms.

CONFLICT OF INTEREST STATEMENT
P.K. and W.K. hold stock in Fresenius Medical Care. P.K. has received author honoraria from UpToDate and HSTalks. The other authors declare no competing interests.

DATA AVAILABILITY STATEMENT
The data underlying this article cannot be shared publicly to protect the privacy of individuals who participated in the study.

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