DL_Track - Automated analysis of muscle architecture from B-mode ultrasonography images using deep learning

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Abstract

B-mode ultrasound is commonly used to image musculoskeletal tissues, but one major bottleneck is data analysis. Manual analysis is commonly deployed for assessment of muscle thickness, pennation angle and fascicle length in muscle ultrasonography images. However, manual analysis is somewhat subjective, laborious and requires thorough experience. We provide an openly available algorithm (DL_Track) to automatically analyze muscle architectural parameters in ultrasonography images or videos of human lower limb muscles.

We trained two different neural networks (classic U-net [Ronneberger et al., 2021] and U-net with VGG16 [Simonyan & Zisserman, 2015] pretrained encoder) one to detect muscle fascicles and another to detect muscle aponeuroses using a set of labelled musculoskeletal ultrasound images. We included images from four different devices of the vastus lateralis, gastrocnemius medialis, tibilias anterior and soleus. In total, we included 310 images for the fascicle model and 570 images for the aponeuroses model, which we augmented to about 1,700 images per set. Each dataset was randomly split into a training and test set for model training, using a common 80/20 train/test split. We determined the best performing model based on intersection-over-union and loss metrics calculated during model training. We compared neural network predictions on an unseen test set consisting of 35 images to those obtained via manual analysis and two existing semi/automated analysis approaches (SMA and Ultratrack).

Across the set of 35 unseen images, the mean differences between DL_Track and manual analysis were for fascicle length -2.4 mm (95% compatibility interval (CI) = -3.7 to -1.2), for pennation angle 0.6° (-0.2 to 1.4), and for muscle thickness -0.6 mm (-1.2 to 0.002). The corresponding values comparing DL_Track with SMA were for fascicle length 5.2 mm (1.3 to 9.0), for pennation angle -1.4° (-2.6 to -0.4) and for muscle thickness -0.9 mm (-1.5 to -0.3) respectively. ICC values between DL_Track and Ultratrack were 0.19 (0.00 to 0.35) for medial gastrocnemius passive contraction, 0.79 (0.77 to 0.81) for medial gastrocnemius maximal voluntary contraction, 0.88 (0.87 to 0.89) for calf raise, 0.67 (0.07 to 0.86) for medial gastrocnemius during walking, 0.80 (0.79 to 0.82) for tibialis passive plantar and dorsiflexion, and 0.85 (0.83 to 0.86) for tibialis anterior maximum voluntary contraction.

Our method is fully automated and can estimate fascicle length, pennation angle and muscle thickness from single images or videos in multiple superficial muscles. For single images, the method gave results that are in agreement with those produced by SMA or manual analysis. Similarly, for videos, there was overlap between the results produced with Ultratrack and our method. In contrast to Ultratrack, DL_Track analyzes each frame independently of the previous frames, which might explain the observerd variability.

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