Skeletal Muscle Segmentation in Thigh MRI using Convolutional Neural Networks: data from the osteoarthritis initiative

Jason Tsang[1,2], Matei Gardea[1,3], Noah Fang[2], Andy K.O Wong[1,4,5]*

1, Centre of Excellence in Skeletal Health Assessment, Joint Department of Medical Imaging, University Health Network, Toronto ON; 2, Western University, London ON; 3, University of California Berkley, Berkley CA; 4, Osteoporosis Program, Schroeder's Arthritis Institute, University Health Network, Toronto ON; 5, Department of Epidemiology, Dalla Lana School of Public Health, University of Toronto, Toronto, ON.

TORONTO JDMI

University of Toronto
Sinai Health System
University Health Network
Women's College Hospital

Introduction

- Leg muscle properties have been associated with knee osteoarthritis (OA) development, progression, function, and pain.
- Segmentation of individual muscle groups with magnetic resonance images (MRI) is currently done manually, which is inefficient and prone to human error.
- We proposed a convolutional neural network (CNN) model trained to segment individual muscle groups from thigh MR images
- Properties obtained from the CNN will be used to investigate future osteoarthritis outcomes.

Methods

MR scans consisted of 15 axial contiguous T1-weighted images of the quadriceps region centered at 100mm above the medial femoral epiphysis

- 2010 MR images from the 36-month visit of the Osteoarthritis Initiative were used to train and test the CNN.

Convolutional Neural Network (CNN)

- 8 separate CNNs were developed from scratch for each individual muscle group, as opposed to further specific training from a pre-trained model.
- CNNs were based on the U-NET architecture with hyperparameters optimization achieved by selection of best performing individual models from each region of interest.

MRI Data Set

- Training images were manually segmented for each of the 8 individual muscle groups including the femur.
  - Rectus Femoris (RF), Vastus Group (VG), Femur, Sartorius (SR), Gracilis (GR), Adductor Group (AD), Biceps Femoris (BF), Semitendinosus (ST), and Semimembranosus (SM).

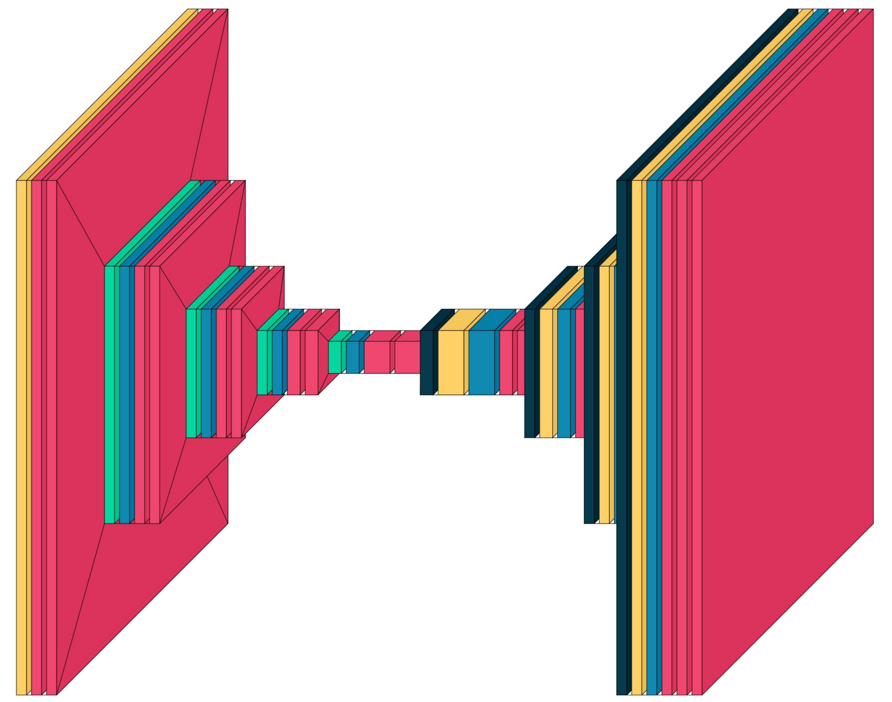

Figure 1. Flowchart of our proposed U-NET CNN architecture. The complete model contains a dedicated CNN for each region of interests (8 CNNs total).

Data Analysis

The two-loss functions used to evaluate model performance were Intersection-Over-Union (IOU) & 1-DICE coefficient.

- Benchmarks were *0.50 & 0.20*, respectively.
- 80% of images were set for training; 20% of images were set for testing
- To measure inter/intramuscular fat within each muscle group, this model was also combined with our Iterative Threshold-Seeking Algorithm (ITSA).

Intersection-over-Union

$$IoU = \frac{Area\ of\ Overlap\ (Intersection)}{Area\ of\ Union}$$

1-DICE Coefficient

$$1 - DICE\ Coefficient = 1 - \left(\frac{2 \times Area\ of\ Overlap}{Area\ of\ both\ objects}\right)$$

Results

- The top three performing muscle segmentation models were the *VG, BF, SM* muscles.
- The IOU scores of the *VG*, *BF*, and *SM* were 0.867, 0.866, and 0.819, 1-DICE coefficients were 0.072, 0.071, and 0.10, respectively.
- The overall mean IOU score across all muscle groups was 0.754 (SD = 0.133) and the mean 1-DICE coefficient was 0.125 (SD = 0.06).
- The mean intermuscular fat volume and percentage were 195.95 cm^3 (SD = 198.64 cm^3) and 19.47% (SD = 8.88%), respectively.

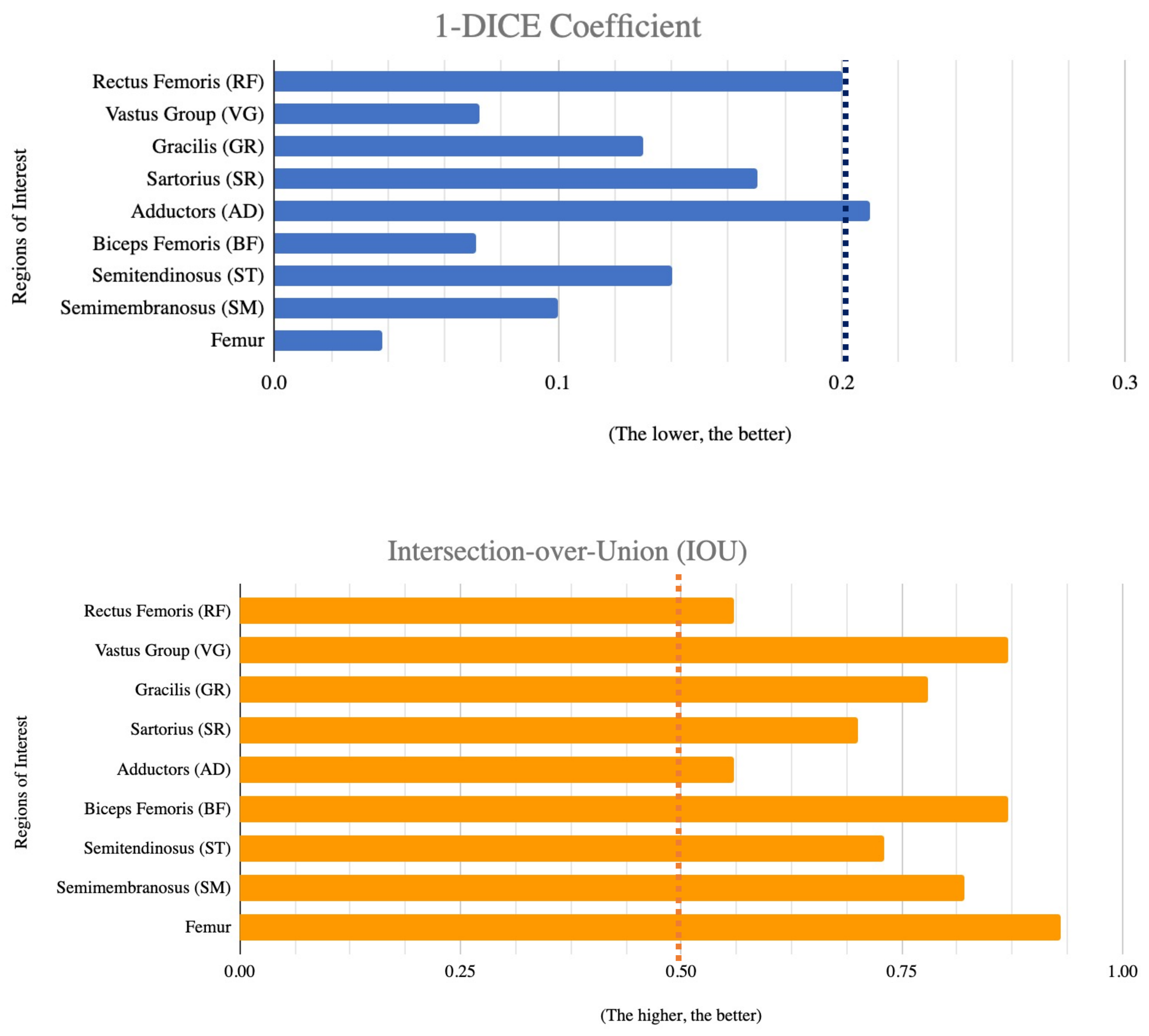

Figure 2. Graphical visualization of the evaluation metrics of the best performing model of each region of interest. Dotted vertical line on each graph represents the pre-determined benchmark.

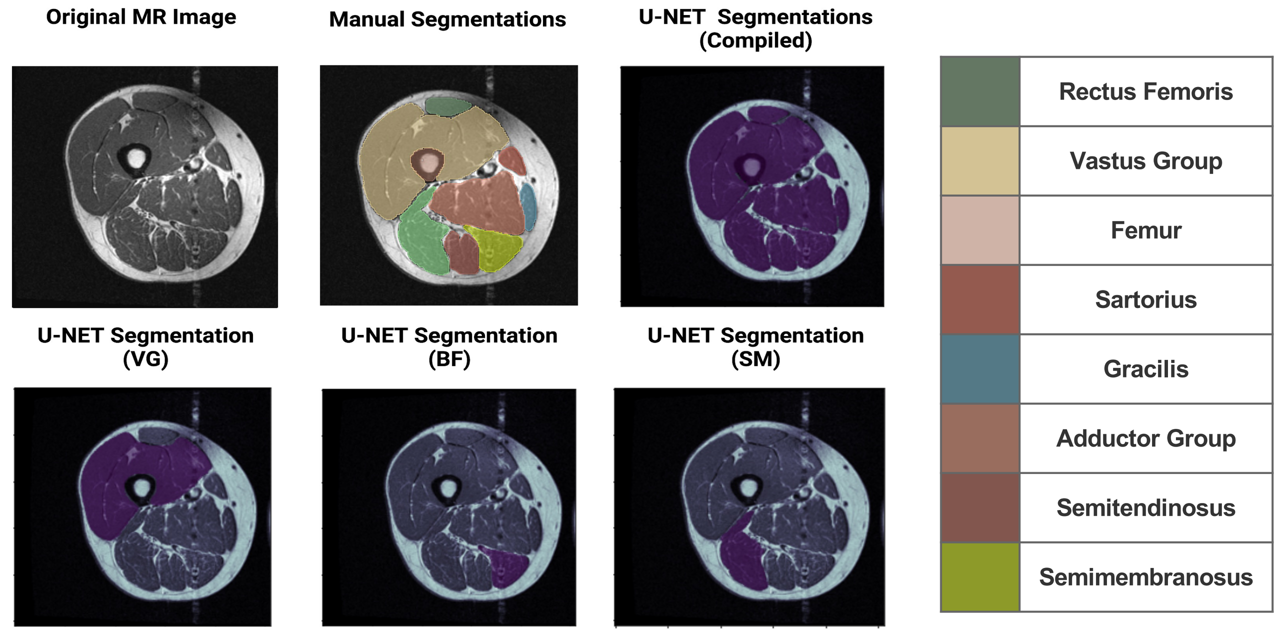

Figure 3. Visual comparison of the original MR image, ground truth segmentations, and CNN generated segmentations compiled. Bottom row shows visual examples of individual muscle group segmentations from the CNN

Conclusion

- This methodological study demonstrated the capability of artificial intelligence to classify individual muscle groups of thigh MRIs with favorable accuracy compared to ground truth segmentations, capturing shape complexities existing among individuals
- Performance of each individual model appeared to be dependent on the complexity of the muscle shape with simpler muscle shapes such as VG and BF performing best
- With further refinement of our CNN and the utilization of ITSA, this method introduces a reliable state-of-the-art method to quantitatively track the progression of muscle volumes and distribution of intramuscular fat, permissive of longitudinal associations with future osteoarthritis outcomes

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Jason Tsang, jgltsang@gmail.com
Matei Gardea, matei.gardea@gmail.com
Noah Fang, nfang3@uwo.ca
Andy K.O Wong, andy.wong@uhnresearch.ca **

Toronto General Hospital Research Institute
Joint Department of Medical Imaging
200 Elizabeth St, 7EN-238A, Toronto, ON M5G 2C4
andy.wong@uhnresearch.ca
416-340-4800 ext. 6276