Diabetic Complications Consortium

Application Title: Quantifying Structural Changes in the Diabetic Foot using Three-dimensional Ultrasound

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1. Project Accomplishments:

This project required significant design and manufacturing of hardware and software, which have largely been completed. With completion of the design and construction as well as significant progress in subject recruitment, our team is well positioned to complete all three aims and prepare results for publication in the next several months.

2. Specific Aims:

SA1) Develop a mechanical system and the necessary software to generate a three-dimensional scan of the entire plantar soft tissue, using B-mode ultrasound for structural information and shear wave elastography for tissue properties.

Progress

We designed a three-dimensional plantar soft tissue scanner using the computer aided design (CAD) software Solidworks (Dassault Systemes, Waltham, MA) (Figure 1). We then used a simplified model to perform a basic finite element model in Ansys Discovery (Ansys, Inc. Canonsburg, PA) to choose the sizes of the components and ensure that the final design would be capable of holding the desired weight with minimal deflection to allow for an effective scan (Figure 2).

The scanner is comprised of two linear actuators and two motors attached using both manufacturer-supplied and custom designed parts. Custom parts were printed on a Stratasys F370 in acrylonitrile styrene acrylate (ASA). This scanning mechanism was mounted on a custom t-slot frame, and the surface of the scanner is one inch thick high density polyethylene (HPDE). A window was milled into the HDPE above the ultrasound probe casing to allow for a thinner pane of low-density polyethylene (LDPE), which mimics the properties of soft tissue slightly better than HDPE. Along the perimeter of the scanner, we added aluminum safety rail to create a more secure environment for subject safety and comfort. The scanner is made from two parts and mounted on locking wheels for improved mobility, as it will be used and stored in different areas.

The scanner itself has largely been constructed and is ready for use.

The software to control the motion of the scanner as well as acquire and save images and metadata was written in MATLAB. The control software was wrapped in a graphical user interface (GUI, Figure 4) for ease of use and enhanced record keeping. The control software includes several features:

- The GUI
    - The graphical user interface includes user-definable fields to describe the type of scan acquired, the subject ID, the subject foot length and width which are used to calculate the scan size, the IP address used to connect to the ultrasound machine and communication port used to connect to the motors.
    - There are 8 check boxes which are used to ensure that appropriate calibrations and procedures have been followed prior to taking a scan. The software will check to ensure these checkboxes have been checked before proceeding with the scan
    - There are 4 imaging parameters that will affect the rate at which the ultrasound image refreshes, which, in turn, affects the maximum speed of the ultrasound. These parameters are presented as radio buttons to allow easy adjustment for the user.
    - Finally, there is a section for notes and observations should there be anything of note to record before or during the scan.
    - All of these parameters are saved in a structure after the scan.
- The control software
    - The scan is controlled by a series of four functions which set up the motors and scan, move the motor in the transverse direction when multiple longitudinal (anterior-posterior) scans are required (i.e., the foot is wider than the 50 mm transducer), send commands to move the motors and take images,

one for B-mode scans and one for shear wave elastography (SWE) scans which require a pause at each location for multiple images.

The scanner also requires post-processing after the images are taken to produce a volume. The largest ultrasound probe for the Aixplorer ultrasound system is 50 mm, while foot widths are typically closer to 75-125 mm. Therefore, 2-3 longitudinal scans will be required to form the whole foot volume. We are currently in the process of testing several methods to stitch longitudinal scans together based on unique features within the images. While the images within the longitudinal scans will be sequential at a regular offset, we anticipate stitching methods incorporating feature matching will aid with motion compensation.

In order to test the scanner during development as well as troubleshoot protocols, we developed a sonographic and radiographic anatomically realistic phantom. We printed a both a gross anatomical shape mold and bony inclusions from ASA on the Stratasys F370. We also printed a gyroid lattice to mimic the plantar fat, which is of particular interest in diabetes. The inclusions were molded in medical ballistic gel (humimic medical, Gel #0) to create a shelf-stable, anatomically realistic phantom.

SA2) Collect plantar soft tissue scans for 7 diabetic non-neuropathic subjects and 7 non-diabetic subjects.

Progress

We have completed IRB approval and have begun recruiting subjects with diabetes. We have thus far identified 6 subjects from the VA clinics who fit our inclusion criteria for our diabetic non-neuropathic group. We have also developed recruitment materials for non-diabetic subjects, however, we anticipate recruitment of these individuals to be less time-intensive so we have not started this recruitment process yet.

We have written a protocol including clinical exam, plantar pressure, computed tomography, and the plantar soft tissue scan and have developed the record keeping materials (i.e., study data collection sheets) required to perform the proposed testing.

SA3) Analyze these scans using segmentation and strain information calculated with digital volume correlation (DVC) as well as an interpretable classification neural network.

Progress

While we do not have the necessary scans to perform this aim yet, we have identified several neural network architectures that will be appropriate to train and deploy. We plan to use the nnUNet (Isensee et. al 2020) for segmentation of 3D scans. The area of interpretable image classifiers is rapidly developing, and as such, we anticipate doing some additional literature review when we begin training a model. We have previously validated a DVC software (StrainMaster, LaVision Inc, Ysplanti, MI) which we will use for DVC analysis.

3. Publications:

There are currently no publications from this work as it is still in progress.