Quantification of Pelvic Floor Muscle Fascicle Orientations from a Cadaveric Specimen Using Photogrammetry

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Background

- Little is known about female pelvic floor muscle (PFM) fascicle arrangement and orientations
- Limitations of MRI and DTI make identifying borders and fascicles of these complex muscles difficult[1,2]
  - Although possible at limited resolutions
- Muscle fascicle orientations are necessary to study and model active muscle contraction, functional disorders (i.e. urinary/fecal incontinence) and physiologic functions (i.e. urination, defecation, childbirth)

Objective

- To robustly quantify PFM surface fascicle orientations for clinical and computational applications
  - Using close-range photogrammetry to overcome limitations of MRI and DTI
- Orientations were quantified as angles within the axial and sagittal planes for clinical application
- A 3D vector field was created by interpolating fascicle tangent vectors for computational application

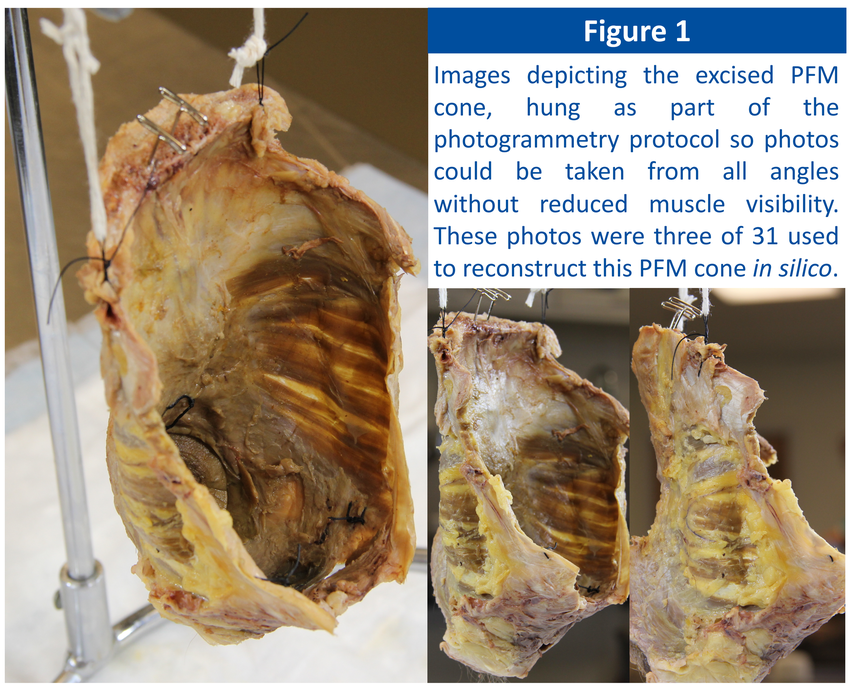

Figure 1

Images depicting the excised PFM cone, hung as part of the photogrammetry protocol so photos could be taken from all angles without reduced muscle visibility. These photos were three of 31 used to reconstruct this PFM cone *in silico*.

Methods: Cadaver Dissection and Photogrammetry

1. The anatomic dissection was performed to expose the coccygeus and levator ani muscles (iliococcygeus and pubovisceral muscles)
   - There were no gross disruptions of the aponeurotic origins or muscles themselves
   - The donor had no history of pelvic floor disorders
1. Anatomical sites were identified to serve as landmarks
   - Ischial spines, symphysis pubis, sacrococcygeal joint and their PFM attachment sites
2. Close-range photogrammetry was used to create 3D textured surfaces of the PFMs *in situ* using Photoscan Pro and nearest point-to-surface correspondences
3. The PFM complex was removed from the pelvis *en bloc* and the close-range photogrammetry protocol was repeated on the excised "PFM cone" (Figure 1)

Methods: Orientation Calculations

1. PFM surface fascicles were traced manually in Blender v2.79b
2. PFM attachments sites were identified, and individual muscles demarcated *in silico* so the coordinates of the attachment sites could serve as landmarks (Figure 2)
3. In Mathematica, the axial plane was defined by the tip of the coccyx and the left and right borders of the pubic symphysis
   - The sagittal plane by the tip of the coccyx, the center of the pubic symphysis, and the midpoint between the ischial spines
4. Tangent vectors were calculated along each trace such that the number of vectors was proportional to its arc length
   - And projected onto the axial and sagittal planes where angles were calculated with respect to the pubococcygeal line
5. Those tangent vectors were inputs into Mathematica's interpolation function to generate a continuous vector field
6. Polar histograms for each muscle and plane were generated in Matlab (Figure 3)

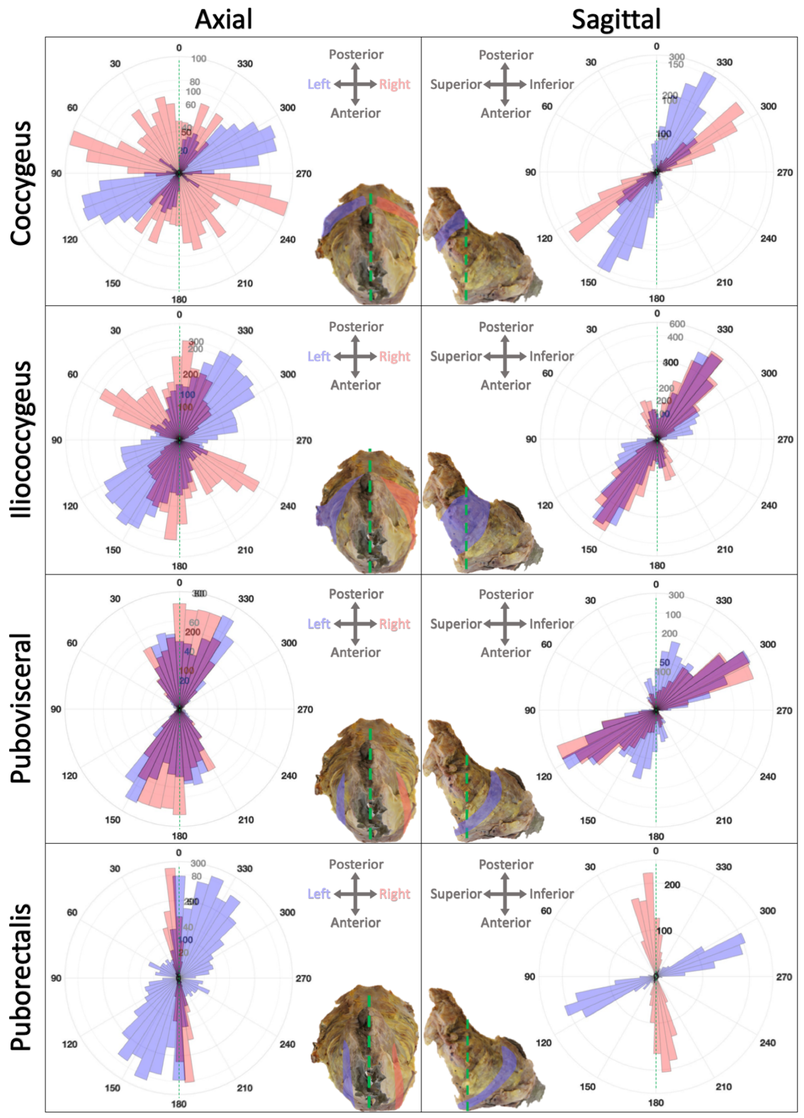

Figure 3

Angle polar histograms with corresponding images picturing the PFM orientations with specific muscles highlighted. Red indicates the right and blue the left side of the PFM cone.

Results

- Muscle fascicles of more proximal components of the PFM complex (i.e. coccygeus) were more laterally oriented
- The average orientation of the muscle fascicles progressively became more anterior-posterior when moving distally (from iliococcygeus to the puborectalis portion of the pubovisceral)

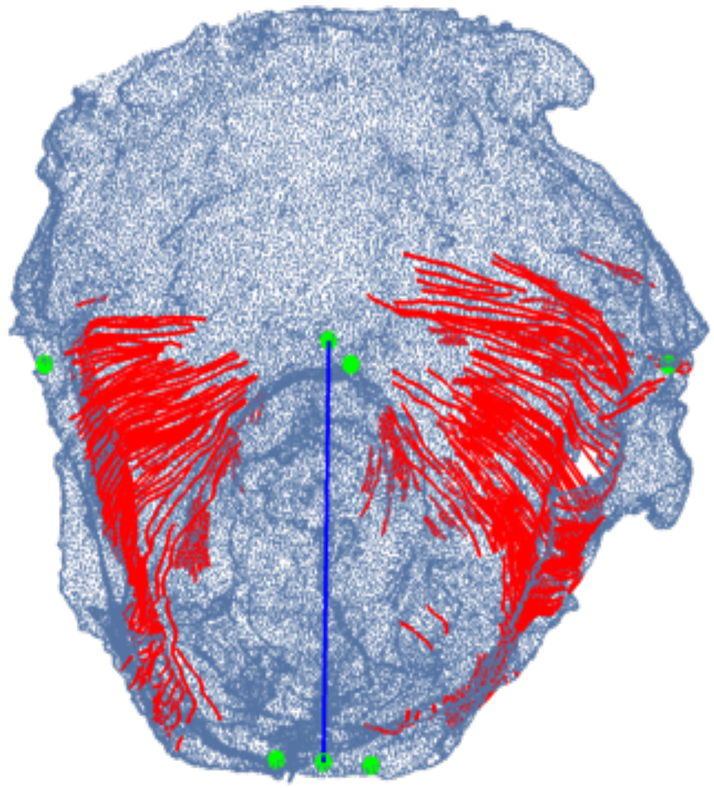

Figure 2

A visualization of the PFM cone, muscle fascicle traces, and anatomic landmarks. Here, the PFM cone is portrayed with a surface mesh (pale blue), the anatomic landmarks are denoted (green points), the pubococcygeal line is shown (dark blue), and the manual traces of muscle fascicles are highlighted (red).

Conclusions

- This method for quantifying muscle fascicle orientations…
  - Allows for intuitive clinical interpretation
  - Outputs data that can be utilized by computational models
  - Could be used to validate DTI to provide more exhaustive orientation data
  - And provides data currently lacking in the field of female pelvic medicine
    - That is essential for a more accurate and complete understanding of female pelvic floor biomechanics
- Though, this method has some limitations
  - Direct orientation calculations are limited to fascicles that can be photographed on muscle surfaces
  - And can only be performed on cadaveric PFMs
- Future studies will validate these results using less detailed, but volumetric, data from *in vivo* imaging

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