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CHARACTERIZING THE MUSCLE/BONE INTERFACE OF THE PELVIC FLOOR MUSCLE USING NOVEL IMAGING TECHNIQUES AND COMPUTATIONAL MODELLING

<u>Hypothesis / aims of study</u>

The aim of the project was to fully characterize the interface of the muscle/bone origin of the pubovisceral muscle using microscopic images, to determine if the arrangement is ideally suited to withstand the high stresses involved in childbirth. The pubovisceral muscle is one of the pelvic floor muscles involved in childbirth. This muscle has to stretch to over three times its resting length during labour, which often leads to stretch-related injury (1) commonly referred to as an avulsion injury. Avulsion of the pubovisceral muscle has been linked to urinary stress incontinence and pelvic organ prolapse later in life (2). In order to fully characterize the muscle/bone interface this project aimed to take microscopic images from the muscle insertion into the pubic bone. The images obtained were then used to create a micromechanical model to explore the effect of the anatomical structure on the loading in this stretch-related injury zone.

<u>Study design, materials and methods</u>

A preserved cadaver from an 88-year-old female, was dissected and the region of interest isolated. The sample was decalcified by placing it in 10 % formic acid for 3-4 days. 30 µm slices were then taken via cryo-microsectioning. The slices were mounted onto slides and imaged using a differential interference contrast (DIC) microscope which uses a light beam shearing interference system to observe structure in unstained samples.

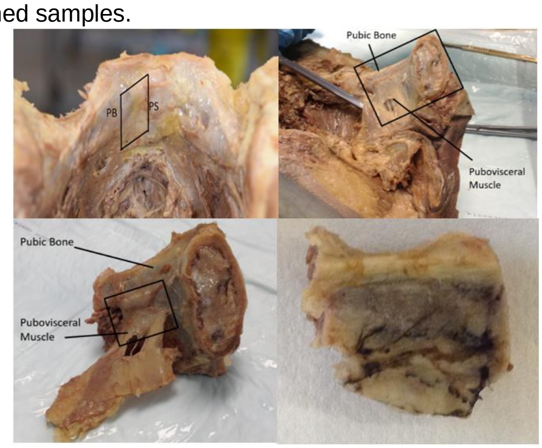

Figure 1: Images showing the process of dissection, PB is the pubic bone, PS is the pubic symphysis and the boxed region, is the region of interest.

<u>Results</u>

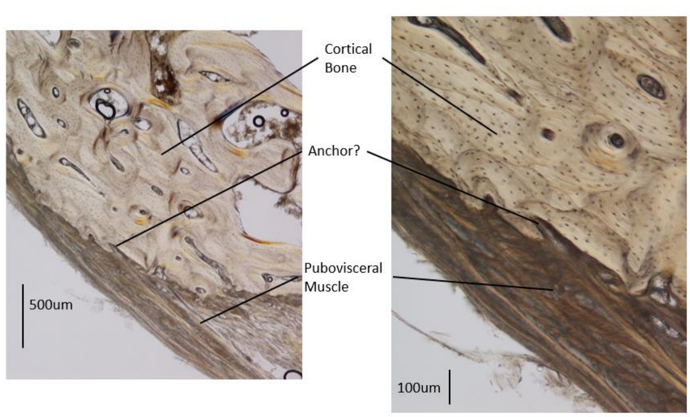

Figure 2: DIC images of sample, left: 4x magnification, right: 10x magnification

The high magnification images (Figure 2) suggests a direct insertion of the muscle fibres into the cortical bone, forming a fibrous enthesis. The unique 'hook like' structures may form part of the load bearing structural arrangement necessary to prevent muscle damage of the interface during childbirth.

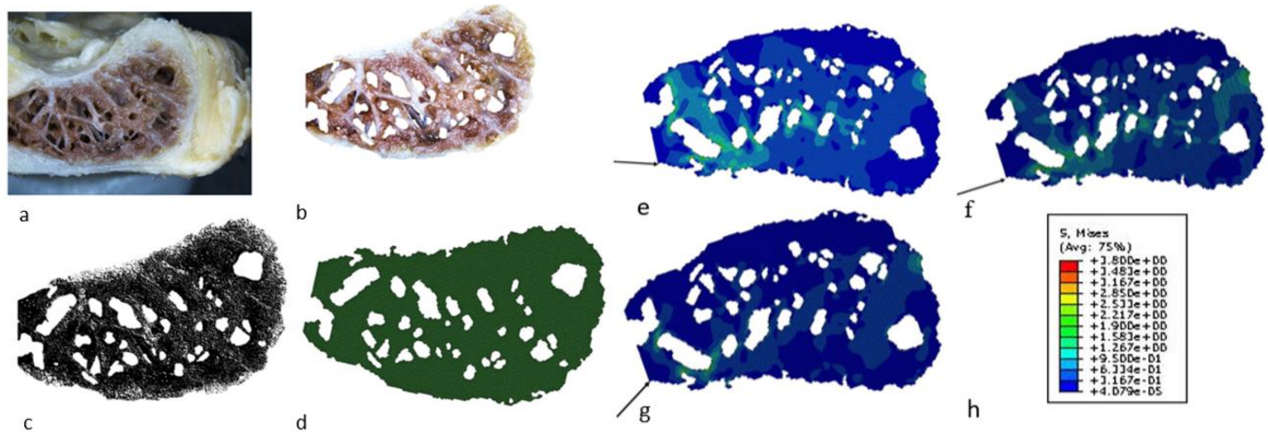

Figure 3: a, macro level image of the pubovisceral muscle and the pubic bone cross-section. b, processed image with the trabecular pores removed. c, binarized image for pre-meshing. d, finite element mesh in Abaqus. e, f, and g, Von Mises stress pattern when the loading direction is approximately parallel, at a 30-degree angle, and at a 60-degree angle, respectively, to the muscle direction, as shown by the arrows. h, the scale bar, numbers represent stress in MPa.

In order to test this structural arrangement a finite element model was created in Abaqus® of the bone structure. Von Mises stress is a measure of damage and is typically used for bone remodelling stimulus. According to Wolff's law, bone resorption will occur in areas of low stress.

The parallel loading direction gives rise to a stress pattern and intensity that appears to support bone loading. The stress patterns produced by the parallel loading direction are more elliptical around the pores, so are consistent with the existing structure.

Interpretation of results

The imaging results have identified a structural arrangement known as a bony fibrous enthesis, where the muscle is inserting directly into the bone without a visible transition zone. Others have found a fibrous enthesis of the periosteal sub-type (1), but this could be due to the age of our sample, as the periosteal layer is known to decrease with age. Fibrous entheses are thought to be more suited to tensional loading (3), making this a possible 'fit for purpose' muscle/bone insertion. Unique 'hook like' structures were identified at the muscle/bone junction, these have not been previously found and may possibly be acting as some form of anchor attaching the muscle to the bone.

The modelling showed that the parallel loading configuration is the most likely loading direction. However, this did not explain why the parallel loading direction observed is unique to this site, this requires further investigation. Future work should model the 'hook-like' features observed in the DIC imaging of the muscle to the bone.

There are limitations to this preliminary study, including the age of the specimen, only one sample was analysed, and difficulty in extracting the exact region of interest. Further work with more samples, possibly from younger, nulliparous women would be desirable.

Concluding message

Despite the limitations of this project, these unique structural findings indicate further research into this area is needed. Additional experimental data would enable a more detailed appreciation of the pubovisceral muscle enthesis and the development of a more sophisticated computational model. This would facilitate a better understanding of the structural role of the muscle/bone interface in the mechanics of childbirth.

References

1. Neurourology and Urodynamics (2011) 1366-1370
2. Am Journal of Obstetrics & Gynaecology (2007) 251 e.1-5
3. Journal of Anatomy (2006) 471-490

Disclosures

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