ULTRASOUND ANALYSIS OF IN-VIVO CONNECTIVE TISSUE DEFORMATIONS OF THE HUMAN ABDOMINAL WALL

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INTRODUCTION

The abdominal wall components, specifically muscle and connective tissue, must meet and accommodate a wide range of force demands for torso movement, spine stabilization, and respiration. The wall is comprised of three muscle groups (internal oblique (IO), external oblique (EO), transverse abdominis (TrA)) and has a composite laminate arrangement that assists torque generation about the three axes and forms stiffening hoop stresses facilitating function. The purpose of this exploratory study was to examine the deformations of the abdominal wall, with a special focus on both the internal oblique aponeurosis and the tendinous intersections of the rectus abdominis (RA), using ultrasound imaging, during relatively simple contractions of the abdominal musculature.

METHODS AND PROCEDURES

Eight healthy males volunteered from the University population. Participants performed a series of static abdominal brace contractions in a modified sit-kneel position, designed to keep the spine in a neutral posture. Target contraction levels were set to 25%, 50% and 100% of the maximum activation capability of the right EO in the testing position. To view the aponeurosis of the IO muscle, ultrasound images were taken with the probe at the level of the umbilicus on the left side of the body, with the lateral position adjusted to ensure a view of the IO aponeurosis between the medial edge of the IO muscle and the lateral edge of the RA muscle. For a sub-set of four participants another series of the identical contractions were performed with the probe at two additional orientations: 1) angled 35 degrees inferior-laterally (along the approximate line of the IO fibres); 2) angled 60 degrees superior-laterally (along the approximate line of the EO fibres). For the RA tendon, the ultrasound probe was positioned over the intersection lying most closely superior to the umbilicus, oriented in the inferior-superior direction along the anterior of the RA muscle, and positioned approximately mid-way between the linea alba and linea semilunaris. Two still ultrasound images were captured on a video cassette and digitized for each trial, the first when the muscles were relaxed and the second when the target activation level had been reached at a steady state. For the IO aponeurosis images trials, the length and thickness of the aponeurosis were measured in both the relaxed (Figure 1) and contracted image (Figure 2). The same measures (length and thickness) were taken for the RA tendon.

Surface EMG was recorded from the RA, EO, and IO muscles, and used to estimate (based on cross-sectional area, maximum stress, and length) the force generated in each of these muscles (along with the TrA) during contraction.

RESULTS

The most unique finding was that both the IO aponeurosis and RA tendon displayed deformations in nearly 50 percent of

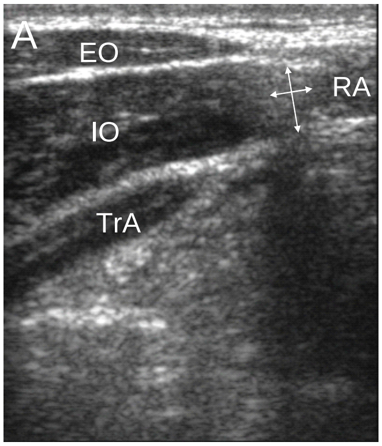

Figure 1. Ultrasound image, taken transverse through the abdomen, of the IO aponeurosis (indicated by arrows) at relaxation.

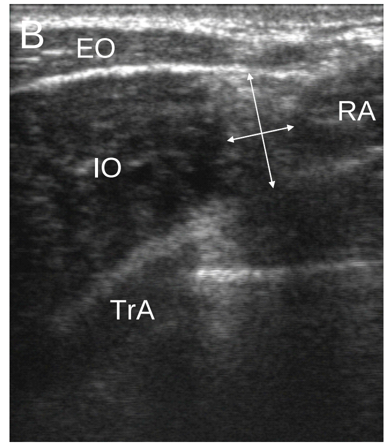

Figure 2. Ultrasound image, taken transverse through the abdomen, of the IO aponeurosis (indicated by arrows) at 100% contraction.

contractions that would be characterized by a simultaneous expansion in multiple planes. Also, the lateral border of the RA muscle was pulled more laterally upon contraction in 68% of trials. The ratio of summed oblique muscle (EO, IO, TrA) force to RA muscle force was used to assess a relationship with the lateral displacement of the RA muscle, with an exponential R-squared fit of 0.54. This indicates that the lateral forces produced by the oblique and transverse muscles dominate over the longitudinal force of the RA muscle, causing the RA to be pulled laterally.

DISCUSSION

The primary finding of this study is that the connective tissues supporting the various attachments to the muscles of the anterior abdominal wall take on a complex arrangement that allow them to deform in complex manners to conform to the different forces acting throughout the system. In particular, the apparent simultaneous tissue expansion in multiple planes is hypothesized to occur as the layered nature of the abdominal wall and aponeurotic or fascial structures allows for such expanding deformations by accommodating separation between the layers in response to the diverse forces acting on the various tissues.

Further, the laterally produced forces of the oblique and transverse muscles appear to dominate the longitudinally produced force of the RA muscle, such that the connective tissues intervening these muscles (specifically the transverse RA tendons and linea alba) must function to accommodate such force distribution.

SUMMARY

This exploratory work has documented unique in-vivo deformations of the human abdominal wall connective tissues that cannot be explained by simple mechanical and tissue properties; a complex network of fibres and matrix interact to accommodate the deformations necessary for varying demands. In particular, the composite laminate nature of the connective tissues appears to allow for expansion and/or retraction in multiple planes simultaneously. In addition, the high laterally produced forces of the oblique and transverse muscles appear to dominate over the longitudinal force of the RA, suggesting a role of the transverse tendons within the RA to transmit hoop stresses around the torso.