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Contribution of the skin, rectus abdominis and their sheaths to the structural response of the abdominal wall *ex vivo*

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ABSTRACT

A better understanding of the abdominal wall biomechanics could help designing new treatments for incisional hernia. In the current study, an experimental protocol was developed to evaluate the contributions of the abdominal wall components to the structural response of the anterior part of the abdominal wall. The specimens underwent 3 dissections (removal of (1) skin and subcutaneous fat, (2) anterior rectus sheath, (3) rectus abdominis muscles). After each dissection, they were subjected to air pressure up to 3 kPa. Ultrasound images and associated elastographic maps were collected at 0, 2 and 3 kPa in the intact state and strains on the internal surface were calculated using stereo-correlation in all states. Strains on the rectus abdominis and linea alba were analyzed. After the dissection of the anterior sheath of the rectus abdominis, longitudinal strain was found significantly different on the linea alba (5% at 3 kPa) and on the rectus abdominis area (11% at 3 kPa). The current results highlight the importance of the rectus sheath in the structural response of the anterior part of the abdominal wall *ex vivo*. Geometrical characteristics such as thicknesses and radii of curvature and mechanical properties (shear modulus of the rectus abdominis, *e.g.* at 0 pressure the average value is 14 kPa) were provided in order to facilitate future modeling efforts.

1. Introduction

Abdominal surgical procedures by laparotomy can create a risk of incisional hernia. The incidence ranges from 2% to 20% (Le Huu Nho et al. 2012). A better understanding of the biomechanics of the abdominal wall could help design better treatments and perhaps reduce the incidence.

Song et al. (2006) and Szymczak et al. (2012) observed the external surface of the abdomen under pressure loading and various postures, respectively. Podwojewski et al. (2013) observed both internal and external surfaces while creating a defect in the wall and repairing it. In all cases, the contributions of the various components of the abdominal wall near the mid-sagittal line were not considered and the abdominal wall was considered as a homogenous material.

The mechanical properties of isolated components such as abdominal fascia or abdominal muscles have been studied by many authors and were found to be different from one another. Uniaxial tensile tests on human samples of linea alba or on rectus abdominis sheath have also been performed (*e.g.* Rath et al. 1996, 1997; Wolloscheck et al. 2004; Grässel et al. 2005; Hollinsky and Sandeberg 2007, Korenkov et al. 2001; Förstemann et al. 2011; Kirilova et al. 2011; Ben Abdelounis et al. 2013). Studies on the abdominal muscles seem less frequent and did not include human samples. Nilsson (1982) and Hernández et al. (2011) characterized rabbit abdominal muscles while Hwang et al. (2005) tested dog lateral abdominal muscles (obliquus externus abdominis, obliquus internus abdominis and transversus abdominis). The results reported in the literature were found to be different from one component to another and show high variations and standard deviations. Moreover the relative contribution of the components to the structural response of the abdominal wall remains unknown.

The aim of this study is therefore to develop a protocol and then evaluate the effect of the abdominal wall components on the structural response of the anterior region of the abdominal wall. Components thicknesses, specimen curvatures and shear moduli of the rectus abdominis were measured in order to facilitate in a future study the simulation of the experimental procedure using a simplified model based on these parameters.

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2. Materials and methods

2.1. Specimens preparation

Eight human anterolateral abdominal walls have been dissected from unembalmed post-mortem human subjects (PMHS, 4 men and 4 women aged from 77 to 98 years). PMHS were donated for scientific usage to the Department of Anatomy of the University of Lyon. All tests and procedures were in line with the French ethical rules and the law that allows experiments with PMHS for biomedical research under the control of a medical school. The specimens were excised from the subcostal line to the pubis and cut laterally by a vertical line joining the lower ribcage and the upper iliac crest (Fig. 1a). Specimens included all layers from skin to peritoneum. They were kept frozen at −20 °C. Approximately 16 h before testing, they were moved to room temperature storage for thawing and kept in gauzes soaked with saline solution until testing.

2.2. Experimental setup

The abdominal wall was maintained in a test fixture initially designed for porcine specimen and described by Podwojewski et al. (2013). The abdominal wall was clamped between an aluminum plate and a rubber ring. The main difference with the previous study was the shape of the hole exposing the abdominal wall (Fig. 1b). An octagonal shape was used because it better matched the shape of the human wall than the triangular shape selected for the porcine study. In this way a maximal area of the abdominal wall could be tested. The umbilical region of the abdominal wall was exposed, excepted for samples 03 and 04 which were centered on the hypogastric region due to their shape. As the abdominal wall thickness was not constant around the hole, the clamps were adjusted to provide adequate tightening in all locations and prevent local sliding during loading. The abdominal wall was not removed from this fixture until the very end of the experiment. The fixture with the abdominal wall was positioned on a custom designed aluminum table creating an air tight compartment (Fig. 2).

The protocol is based on successive dissection techniques. All dissections were performed by a visceral surgeon. Similarly to a laparoscopic procedure, air pressure (from 0 to 3 kPa) was applied to the peritoneal surface of the same specimen in 4 dissection states (Fig. 3):

A. intact
B. after dissection of the skin and the subcutaneous adipose tissue
C. after dissection of the anterior rectus sheath
D. after dissection of the rectus abdominis.

2.3. Measurements

The linea alba and the rectus abdominis are oriented along the cranio-caudal axis which will be referred to as longitudinal direction. The medio-lateral direction will be referred to as transverse direction. Muscular fibers of the rectus abdominis are parallel to the longitudinal direction while the collagen fibers of the linea alba and the rectus sheaths are mainly oriented parallel to the transverse direction.

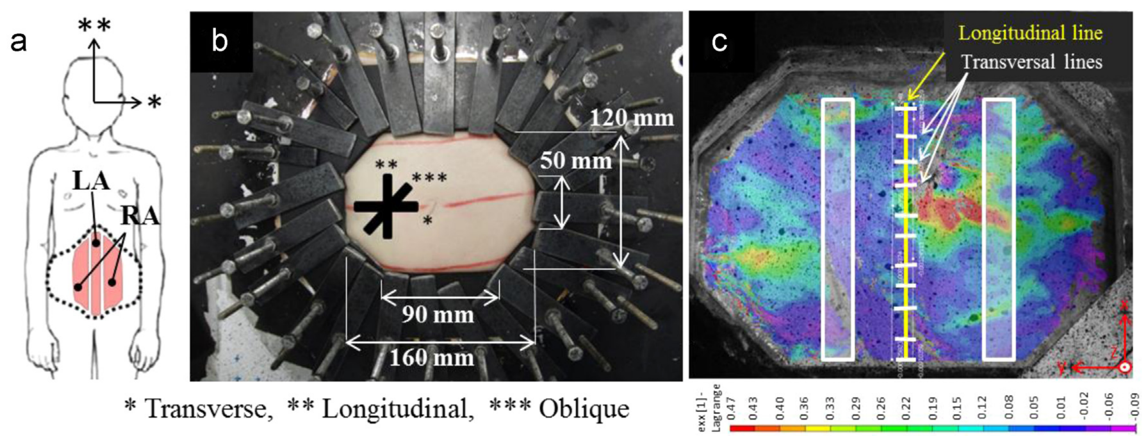

Fig. 1. Specimen preparation (a) specimen excision line (dotted line) and position of the rectus abdominis muscles (RA) and the lina alba (LA), (b) view of the external side of the specimen with ultrasound locations (black lines), and (c) view of the internal side of the specimen with strain map and locations used to compute average strains.

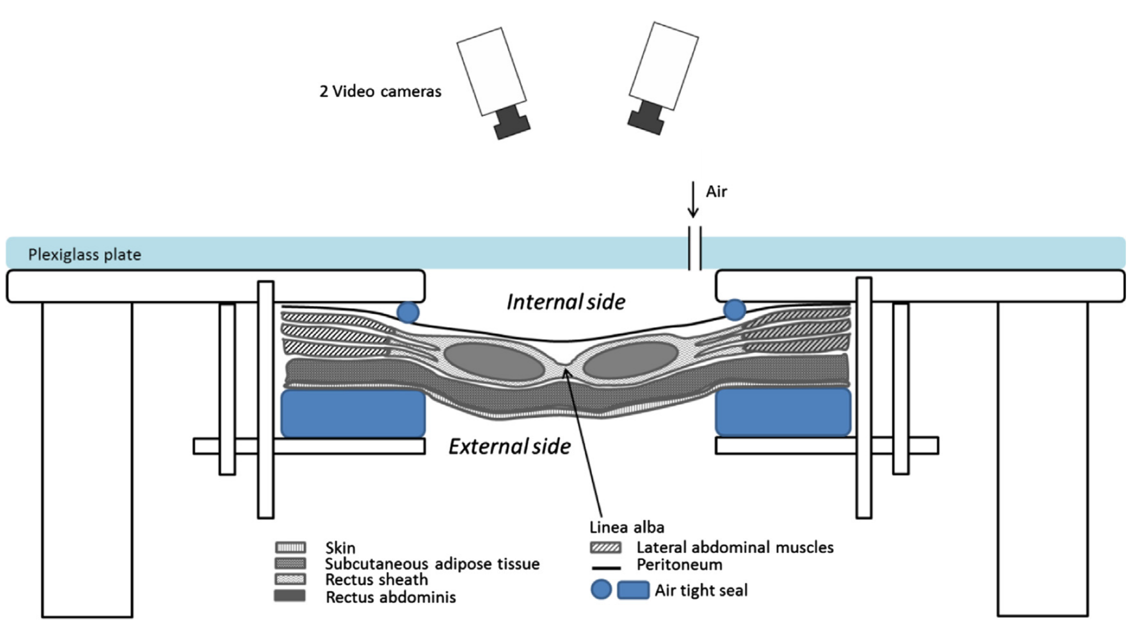

Fig. 2. Experimental device for the pressure loading of the abdominal wall and video set-up for strain measurements.