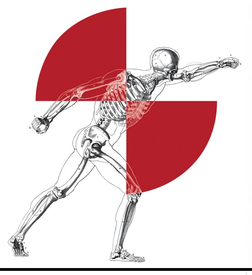

Characterization of Loading Environment on Human Ribs during Respiration

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INTRODUCTION

- Respiration is a combination of air flowing in and out of lungs during inhalation and exhalation, resulting from a change in the pressure differential. Breathing is aided by the muscles of respiration and subsequent movement of the ribs, which change the volume of the thoracic cavity. Movement of the thoracic skeleton results in differential strain on ribs, potentially causing microfractures. Microfractures can weaken the structural integrity of the rib, increasing its susceptibility to fail.
- The rib cage is composed of 12 ribs per side: 7 true ribs articulating directly with sternum, 3 false ribs attached via costal cartilage, and 2 floating ribs (Figure 1). Each rib has a cutaneous and pleural cortex, and the length can be divided into 3 sections: Posterior = 30% of curve length (Cv.Le), Lateral = 60% of Cv.Le, Anterior = 90% of Cv.Le (Figure 2).

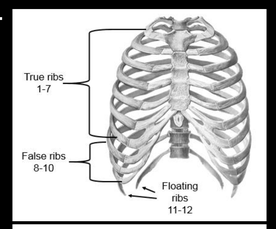

Figure 1. Labeled Rib Cage

- No investigations have been conducted to determine normal strains experienced by the ribs during respiration. The pleural side of rib could experience a different strain mode than the cutaneous side, and different locations along the rib length could experience differences in strain magnitudes.

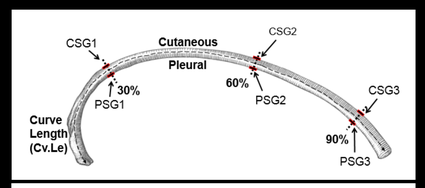

Figure 2. Labeled Rib

- **The objective of this study is to compare strain values between bilateral rib pairs during respiration, quantify variations in strain mode between the posterior, lateral, and anterior aspects of the rib, and note differences in strain magnitudes between the posterior, lateral, and anterior aspects of the rib.**

METHODS

Study Sample (n=1)
- Post Mortem Human Subject
  - Male, 75 years old
  - 68 inches, 183 pounds; BMI = 28
  - Lumbar aBMD t-score = 1.9
  - No history of invasive thoracic surgery

Phase I: Previous Research
- Previous research studies strains in the chestband of 50th percentile male volunteers

→ **Phase II: Cutaneous Strain**
- Measures strain on cutaneous surface of ribs using strain gauges and uses a chestband to match the chestband strains from Phase I

↓

Phase III: Pleural Strain
- Measures strain on pleural surface of ribs using strain gauges using an air bladder to match strains of the cutaneous gauges from Phase II

← **Phase IV: Next Steps**
- Identification of strain modes (tension vs compression) and magnitudes during normal respiration = understanding of loading environment rib is adapted to

METHODS CONTINUED

Breath Pattern
- Normal breath duration = 3 seconds, pressure = 14.6 psi.
- Deep breath duration = 6 seconds, pressure = 14.7 psi.
- The pressure during testing will be increased until chestband data matches *in vivo* data. The need for increased pressure results from the lack of movement of the diaphragm and other inspiratory muscles during testing.

TEST MATRIX

Test #	Breath Pattern	Instrumentation
1-4	Normal (x3), Deep (x3), Normal (x3)	Chestband & Cutaneous Strain Gauges
5-8	Normal (x3), Deep (x3), Normal (x3)	Cutaneous Strain Gauges only
9-12	Normal (x3), Deep (x3), Normal (x3)	Cutaneous & Pleural Strain Gauges

Instrumentation
- Chestband placed on the axillary region of the sternum (Figure 3).
- During Phase II the strain gauge placement consists of strain gauges on the manubrium and body of the sternum, as well as 3 strain gauges on the cutaneous side of the rib at the 30%, 60%, and 90% of the rib positions (Figure 4).

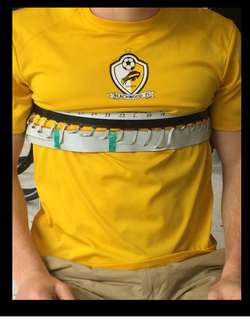

Figure 3. Volunteer with Chestband

- During Phase III an additional 3 strain gauges will be placed on the pleural side of the rib at the corresponding 30%, 60%, and 90% positions.

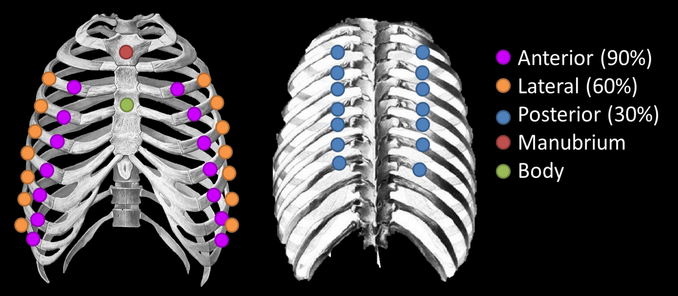

Figure 4. Anterior view (left) and posterior view (right) of rib cage

Phase II: Cutaneous Strain:
- Instrumentation consists of a chestband placed on the axillary region of the sternum and 42 general purpose strain gauges (VISHAY Measurement Group, CEA-06-062UW-350, Raleigh, NC) installed on cutaneous side of bilateral ribs 3-9.
- Respiration will be simulated using a compressed air pump to inflate the lungs. The pressure will be adjusted until strain gauge data matches chestband data from Phase I.

Phase II: Pleural Strain:
- Thoracic organs will be removed to gain access to thoracic cavity and 42 strain gauges will be installed on pleural side of bilateral ribs 3-9. A nitrile inflatable bag plug will then be used as an air bladder and inserted into the thorax to replicate breathing.

Data Acquisition:
- DTS Slice Pro (Diversified Technical System, Seal Beach, CA) will collect the strain gauge data during testing and CrashStar will be used to analyze the chestband data. The rib strain gauge data will be compared between the 3 positions on rib to look for change in strain mode. The data will also be analyzed for variations in strain magnitudes between the 3 positions on rib, the bilateral ribs, and the cutaneous and pleural sides of ribs.

EXPECTED RESULTS

- Phase II will be verified by matching chestband data with Phase I results. The preliminary results from the cutaneous strain gauges will show variations in strain in the ribs. It is expected that the bilateral pairs of ribs will experience higher strain on the right side of the thorax than the left due to the size difference in the lungs.
- Phase III will be verified by matching strain gauge data from Phase II. After analyzing the pleural strain gauge data in combination with the cutaneous strain gauge data, it is expected that the ribs will experience a straightening effect during respiration producing compression on the cutaneous cortex and tension on the pleural cortex. Additionally, the greatest strain is anticipated to be on the sternal side of the rib and will decrease along its length towards the vertebral side due to the expected motion of rib bending during inhalation

CONCLUSIONS

- This study is necessary to create a baseline for rib strain in a regular loading environment. The next steps would be to conduct the cutaneous and pleural strain tests, then analyze the resulting data to determine variations in strain. Use of these data could significantly improve biofidelic modeling efforts.
- Identifying the normal range of strain modes and magnitudes that the ribs are adapted to can lead to increased understanding of rib behavior during abnormal loading scenarios.

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