Biomechanics of the Unstable Thorax

Respiratory Work and Intrathoracic Volume Changes in Segmental Rib Fractures

Julian N. Zierke [1], Georg N. Duda [1], Philipp Damm [1], Mark Heyland [1], Marcel Niemann [1,2]

[1] Julius Wolff Institut, BIH at Charité, Berlin, Germany [2] Centre for Musculoskeletal Surgery, Charité - Universitätsmedizin Berlin, Germany

INTRODUCTION

A relevant proportion of severely injured patients suffer from **thoracic injuries**. Unstable bony thoraces (**flail chest**) as a result of multiple segmental rib fractures are associated with particularly high morbidity and mortality [1-3]. To date, there is **no uniform treatment recommendation**, but early surgical stabilisation appears to shorten the invasive ventilation time and hospital stay and reduce the incidence of pneumonia [4]. Conservative treatment can yield satisfactory results for some patients, avoiding surgical complications [5].

OBJECTIVES

- Gain extended understanding of the biomechanics of flail chest injuries
- Investigate the correlation between the size of the flail segment and tidal volume and the need for compensatory respiratory work

MATERIAL AND METHODS

- Biomechanical "digital sibling" from injury CT data of a representative patient
- Creation of finite element analysis (FEA) of the bony thorax and lung (Figure 1)
- Material properties, boundary conditions and pressure gradients were estimated from the literature to generate physiological breathing patterns
- FEA for a range of segmental fracture situations under inspiration to show clinically realistic changes in thoracic wall movement with typical paradoxical movement of bone segments in the fracture area (Figure 3)
- Fracture scenarios modelled with short (Figure 2, purple) and long segments (Figure 2, red):
  - (i) 4th; (ii) 4th and 5th; (iii) 3rd, 4th, and 5th rib
- Quantitative comparison parameters:
  - Tidal volume change and required mechanical respiratory work
  - Relative loss of tidal volume and theoretical compensatory respiratory work related to the intact model

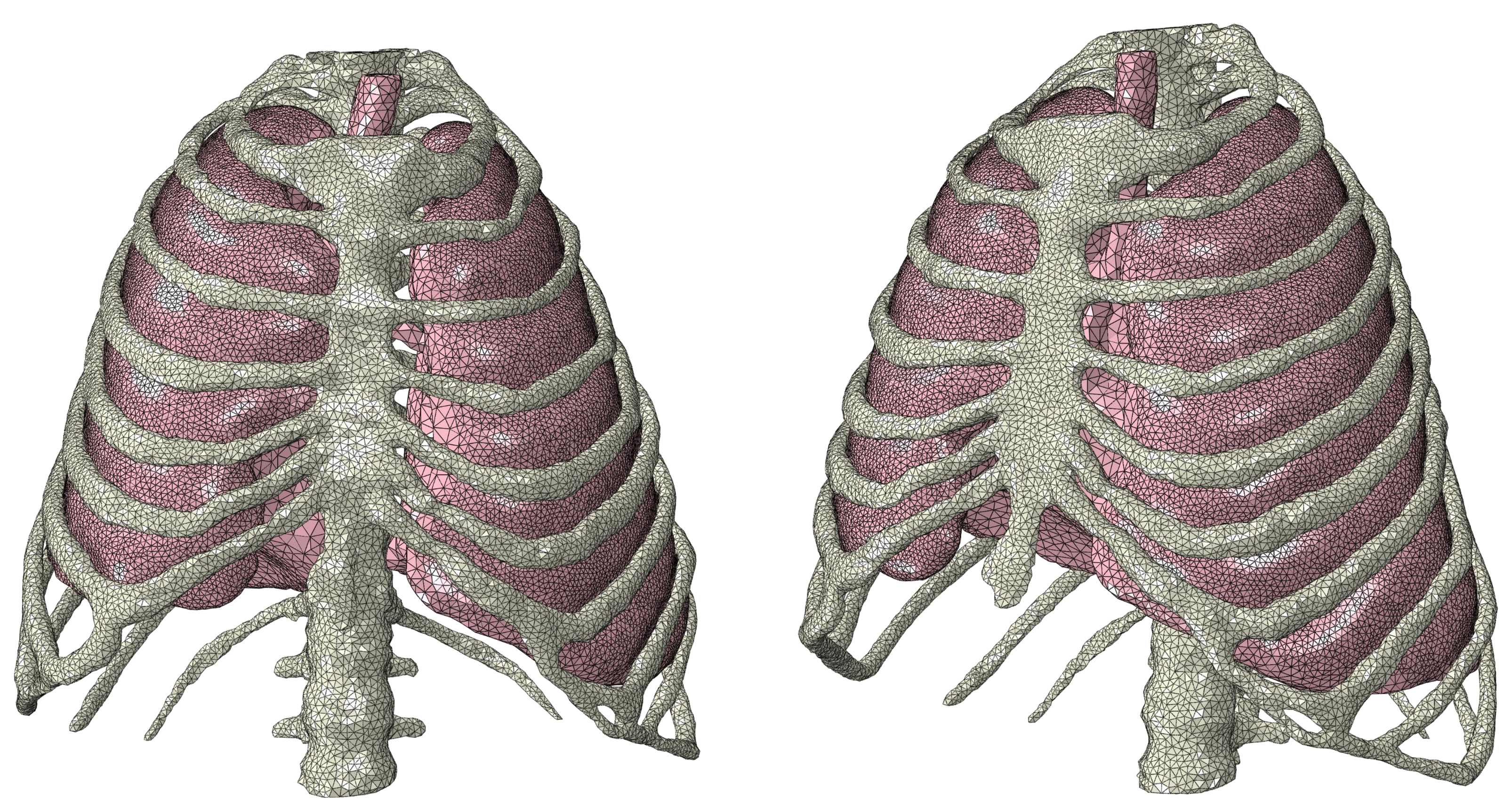

Figure 1. Meshed finite element model of thorax and lung.

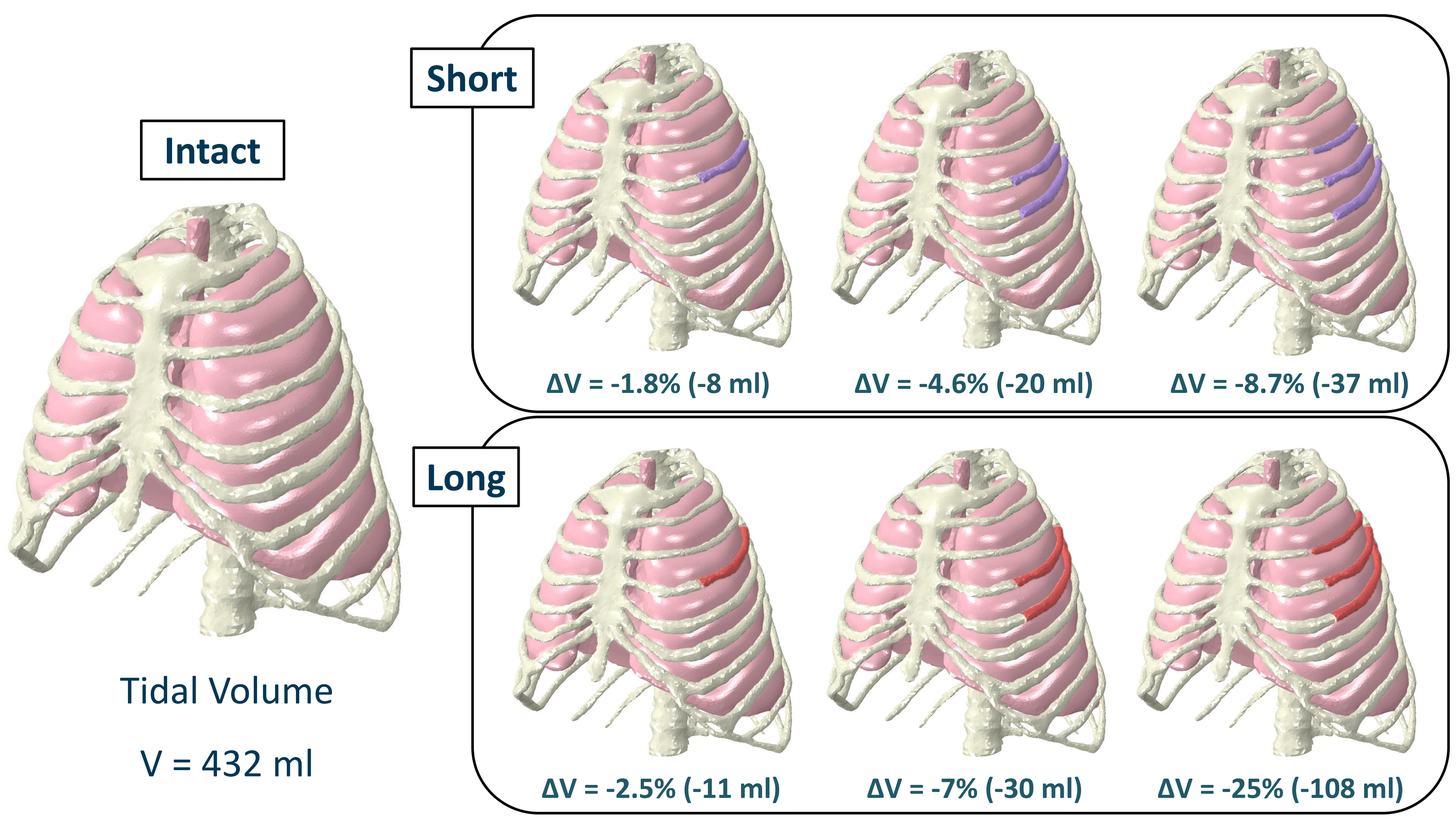

Figure 2. Relative loss of tidal volume in comparision to the unfractured reference model.

RESULTS

- The extent of segment movement varies between fracture configurations
- Larger segmental defects were significantly associated with:
  - Lower tidal volume, with a loss ranging from -8 ml to -108 ml (Figure 2)
  - Higher compensatory work (Figure 4)

Scan for Animation!

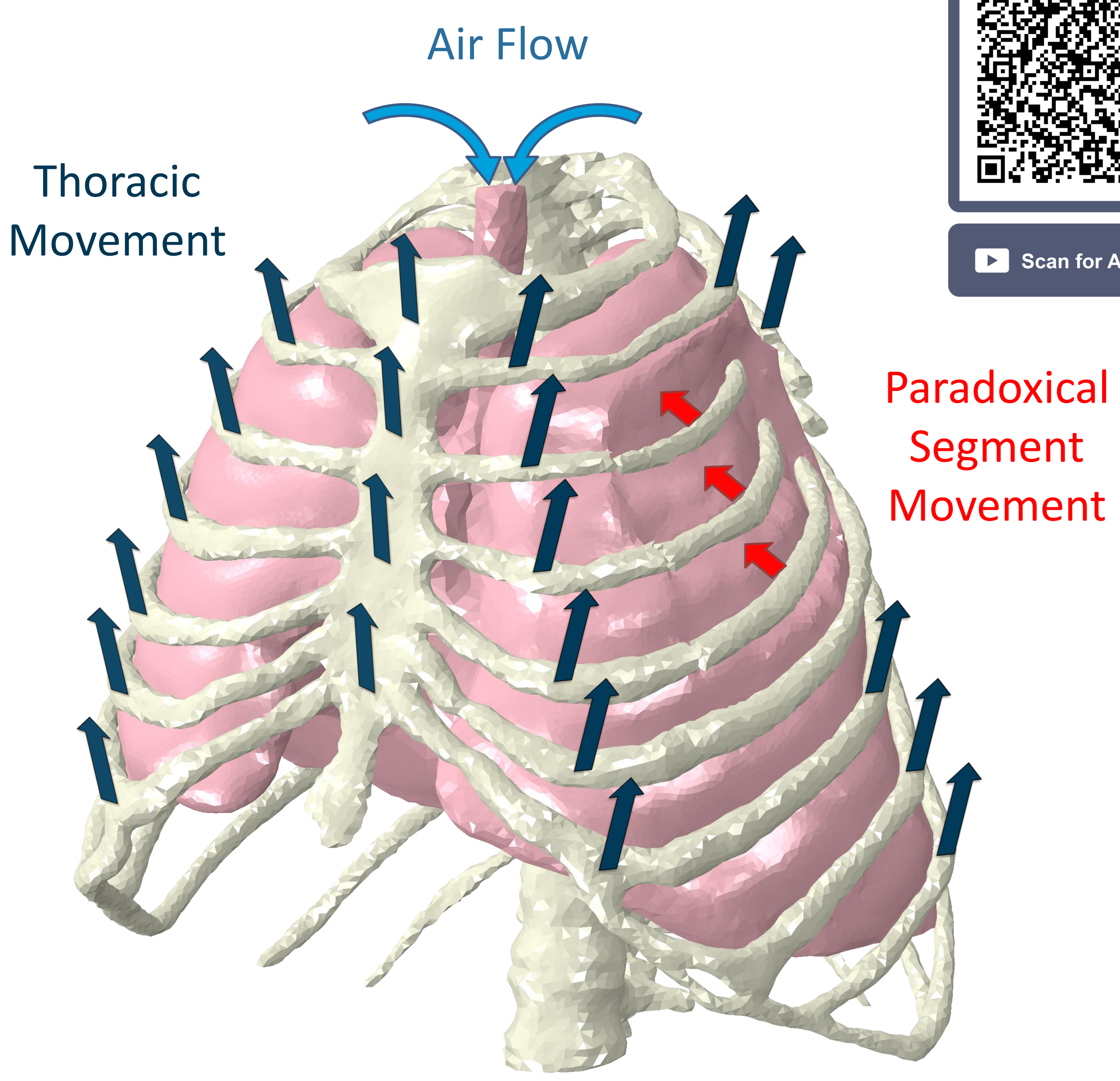

Figure 3. Schematic illustration of the thoracic and paradoxical segment movement during inspiration.

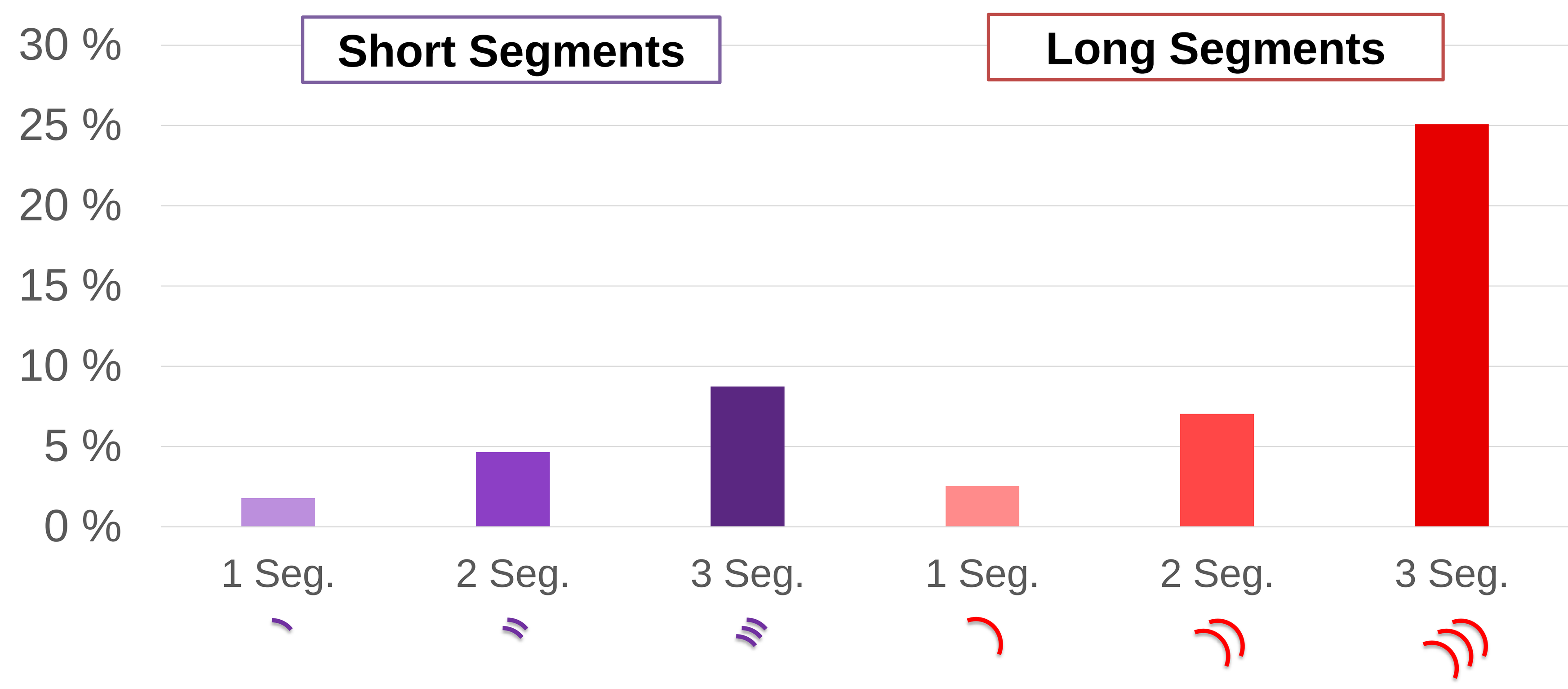

Figure 4. Theoretical compensatory respiratory work for different fracture configurations or number of segments (Seg.) in comparision to the unfractured reference model.

DISCUSSION

This study provides a **first insight** into the **biomechanical behaviour** of the unstable thorax. It shows that thoracic **volume loss increases** with the number of fractures and the size of the affected segment. In addition, the performance of the thorax decreases as the area of the affected segment increases, resulting in an **increased workload** for the patient with each breath. This implies that the **indication for flail chest stabilisation** should be based on both the **defect number** and the **segment size**. However, these findings have limitations. The study was based on a single representative patient, modelled only the inspiration phase and used idealised boundary conditions.

REFERENCES

[1] Topp et al, European Journal of Trauma and Emergency Surgery, 2012; [2] Schulz-Drost et al, The Thoracic and Cardiovascular Surgeon, 2017; [3] Van Breugel et al, World Journal of Emergency Surgery, 2020; [4] Coughlin et al, The Bone & Joint Journal, 2016; [5] Zhang et al, Journal of Cardiothoracic Surgery, 2015