Three-Dimensional Tracking of Chest Wall Deformation during Cardiopulmonary Resuscitation using Tagged MRI

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Purpose
The motivation of this study is to quantify, for the first time ever, the 4D strain and displacement fields generated by cardiopulmonary resuscitation (CPR). A full understanding of the deformation may allow for the development of a more strategic force application method and lend insight into the mechanism of forward flow during CPR.

Introduction
In the United States alone, more than 300,000 people die every year from sudden cardiac death. The goal of cardiopulmonary resuscitation is to improve survival and quality of life for these arrest victims. It is clear that the application of force to the sternum causes deformation to the chest wall, which in turn generates the blood flow crucial for survival. Previous work to understand the chest wall deformation during CPR has mostly been limited to simple viscoelastic models [1]. This study used tagged MRI to gain accurate quantitative and qualitative information about this critical deformation.

Methods
Imaging:
An unpreserved adult female cadaver was fitted with a chest compression device, consisting of a bladder-containing vest that is cyclically inflated (frequency of 1 Hertz) using a pneumatic system. The cadaver was then placed in a real-time cardiovascular scanner and imaged during chest compressions using a gated fast-card gradient echo sequence (TR = 6.5, TE = 1.7, flip angle = 10, 256 frequency encoding steps, 256 phase encoding steps, field of view = 40 cm x 40 cm, slice thickness = 10 mm, tag spacing = 10.9 mm). Cardiac gating was achieved through a sinc output from the compression device that indicated the opening of a valve and initiation of compression. Imaging was performed over an entire compression cycle. Twenty-nine axial slice sequences were collected with 34 time phases. Each axial image contained an orthogonal set of grid tag lines which spanned the entire chest. Oblique images were acquired perpendicular to the axial images every 12 degrees in a star pattern.

Deformation Tracking:
For all short axis and long axis images, the outer chest wall boundary and inner chest wall boundary (formed by the ribcage) were interactively contoured using the XBS3 program by Schecter[2]. Tags were detected semi-automatically in each image using a tag detection algorithm by Guttman[3]. The tagged tissue was tracked with a 4D B-spline method [4] that combined the 1-D displacement information from each tag set over time.

Results
From the 34 phases that were initially collected, tag integrity was sufficient to track motion over the first 12 phases which included the full compression but no relaxation (Fig 1).

Fig 1. Reference and deformed axial images during chest compression

Tissue tracking was completed using the 4D B-spline method for these 12 phases. The residual errors on the tag tracking was 1.75 mm ± 1 mm.

Discussion
This study demonstrates that it is possible to acquire tagged MR images during CPR chest compressions. These tagged images can then be processed to generate quantitative four dimensional chest wall deformation and strain profiles. The ability to track chest wall mechanics with high spatial and temporal resolution during CPR may lead to new compression algorithms and lend insight into the mechanism of efficient CPR.

References