A new method to assess the deformations of internal organs of the abdomen during impact

P. Beillas^{*}, C. Helfenstein^{*}, F. Rongieras ^{*+}, A. Le Ruyet^{*},
F. Berthet[°], M. Tanter[‡], J-L. Gennisson[‡]

^{*} Univ. de Lyon; IFSTTAR, LBMC, Bron ; Univ. Lyon 1,

+ Hôpital Desgenettes, Lyon

° Lier-Transpolis, Lyon Saint Exupery

‡ Institut Langevin, ESPCI ParisTech, Paris

Université Claude Bernard

Lyon 1

IFSTTAR

Background and objectives

- Context: automotive safety: Abdomen can be subjected to large & rapid compressions
 - Internal response difficult to observe (organ; region) → validation of modelling assumptions & injury mechanisms?
- Recently: Howes et al. (Stapp, 2012)
 - High speed bi plane Xray → 3D trajectories of implanted targets
- Objectives: Develop complementary protocols to observe the internal response of isolated organs or full abdomen
 - Approach: ultrafast ultrasound imaging.
= here: 5000 images per second
 - Aixplorer (Supersonic Imagine)
 - Drawback: image quality reduced compared to classical B mode
- Two protocols presented: kidney + full body

Howes et al. (2012) setup

Material and methods

- Isolated organs: compressive testing of porcine or human kidneys
 - Fresh organ, perfused at 80mmHg into artery
 - Loading at 0.003 (non-destructive) and 0.3m/s (up to failure)
 - Linear ultrasound probe (0.2x0.2mm, up to **5000 images/s**)

Material and methods

Full body impacts: 5 PMHS with test to test improvements. Typically:

- Preparation (Day 1 after thawing):
 - Incision on linea alba
 - Tracheotomy for lung inflation
 - Catheter in iliac artery for perfusion
 - Gas removed from intestines, antibiotics+saline injected
 - Colon emptied and filled (gel)
- Test setup:
 - Inverted mount (Howes et al., 2012)
 - Adjustable impact location, stroke & speed (1 to 7m/s)
 - Cylinder (tip: flat or sphere), belt
 - Curved probe (192 elements) on positioning arm (subject) or inside impactor ~2000 images/s

Material and methods

Full body impacts (cont'd)

- Testing (day 2): lungs inflated prior to each test. 2 regions of interest :
 - 1) **descending colon** ~axial plane; cylinder or belt, limited stroke, no perfusion
 - 2) **liver/diaphragm** ~sagittal plane
→ Removal of 2 floating ribs;
 - a) cylinder or belt, limited stroke, no perfusion
 - b) Cylinder, large stroke, perfusion
- Total: up to 20 tests per subject...
- Instrumentation and geometry :
 - Force, acceleration, cameras...
 - CT-scan, surface scan, B-mode

Results: isolated kidney

- Example of test up to failure
 - sudden motion towards peak force → time of failure
- Uniaxial strains by zone (target tracking) always possible
- E.g. effect of strain rate (paired tests on porcine organs)

Results: isolated kidney: strain maps

- Challenges: noise, possible through plane motion... (Typical 2D correlation not ok...)
- Approach developed: (1) automatic target tracking (Preibisch et al., 2010) (2) FE model based interp.
- Preliminary results:
 - Predicts manual target tracked
 - Strain map respecting boundary conditions...
 - Need more validation work...

Preibisch et al. (2010).
Nature Methods

Results: Full body tests - liver (subject 3)

Results: liver (subject 5)

- Effect of velocity (movies frame rate adjusted for velocity difference)

3m/s, 2000im/s

6m/s, 2000im/s

Approximate position

Results: dual probe

- Colon and ... kidney (subject 2)
 - Difficult to understand...

- Liver: results more promising (subject 4)...

~2000 images per second

Results: colon (subject 1)

Colon
Compression

SPH for
hollow organs

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Discussion

- New protocols developed/applied to isolated kidneys and 5 PMHS
 - First quantifications, preliminary simulations
 - Organ: non censored data? Whole body: mostly no abdo. injury

Challenges and limitations

- Numerous technical issues (trigger, software, ...) now solved
- Careful planning required (image quality/depth, through plane motion)
- PMHS model (not a live subject) and ultrasound requirements ...
 - Gases: mostly solved (inverted body, gel) → response?
 - Lung pressure helps control diaphragm position but risk of air leakage in abdomen, position of intestines?
 - Perfusion issues whole body
 - Floating rib removal for liver imaging
 - Note: may have occurred in past testing without being noticed

Conclusions and Perspectives

- Approach is promising...
 - Seems flexible to study other PMHS configurations (e.g. isolated liver, side impact, thorax flexion) or volunteer
- Exploitation of available results: human FE model validation, strain maps processing
- Continue testing to increase sample numbers
 - + some methodological improvements
 - dual probe setup, 3D probe...
 - Whole body: perfusion, non frozen PMHS

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