A finite element model of the upper extremity has been developed in order to study the biomechanics of the shoulder in different configurations:
- In physiological condition, to understand the kinematics and the mechanical behaviour of the complex (stress, strain and effort in different positions, loading and motions),
- During an impact solicitation, to study precisely the injury mechanisms and to improve the road safety,
- At least, in the case of a replacement of the shoulder joint by prosthesis, to understand the biomechanics of this modified structure and to analyse the influence of the implant design.

For that, we reconstructed the geometry of the bones and articular structures of the shoulder from CT scan dataset, and we meshed them with more than 250 000 elements via Hypermesh software. Then, we integrated the mechanical properties of each element with Radioss process. Currently, we are validating this model with numerical simulations: dissociated tests on each structure (bones principally) and global test on the shoulder bone complex during a lateral impact.
A numerical model of the shoulder

Introduction

An observation in France: (2006)

Road accidents: more than 4700 deaths

Daily living accidents: almost of 10 000 deaths

A main injury: the shoulder

- 35% of fall
- 65% of lateral car crash (Frampton, 1997)

Causes:
- 1st point of contact with the external wall structures
- High energy
- Lack of safety measures

Several pathologies, physical handicaps and residual disabilities

LBA (INRETS). Project of an advanced Finite Element Model of the human body in order to study these accident effects:
- Injury mechanisms (genesis)
- Applied loads
- Behaviour of different structures

Objective: Study the behaviour and failure process of shoulder joint during various solicitations.
A numerical model of the shoulder

**Problem definition**

Current model:
- too simple for the shoulder joint
- not so accurate to study locally injury mechanisms
- single application

To study accurately the shoulder joint

Develop an advanced FEM of the shoulder for:
- Trauma investigation
- Kinematics analysis
- Biomedical and orthopaedic surgery
- etc.
Shoulder: Hanging joint, large mobility and instability.

Complex structure with many stresses and strains.

**Analysis**

- **Anatomy of shoulder**

  Shoulder: Hanging joint, large mobility and instability.

  - **Bones**
    - Ligaments
    - Articular part
    - Muscles
A numerical model of the shoulder

- Development of the model

1. Generate a 3D structure

From CT scan images, 70 years old patient, 50th percentile without pathology

- Identify the anatomical structures with anatomists
- Draw the contours of each part precisely
- Generate a 3D structure with an algorithm from the laboratory (Bidal, 2003)
2. Mesh the geometric structures

- **Cortical bone**:  
  - Shell elements of 1 mm  
  - Optimise the thickness of cortical shell (from the internal and external contours of bones)

- **Spongious bone**:  
  - Tetrahedral elements  
  - Localisation of the spongious zone from dry bone cuts  
  - Anatomic distribution of spongious meshing  
  - Meshing continuity with cortical bone
3. Integrate mechanical behavior

- **Mechanical parameters of bones**
  
  - Dual material (cortical + spongious)
  
  - Elastoplastic behaviour
  
  - Dataset range from literature

<table>
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<th>ν</th>
<th>σ(_y) (Mpa)</th>
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<td>100 - 3500</td>
<td>0.26 - 0.3</td>
<td>7 - 10</td>
<td>15</td>
</tr>
</tbody>
</table>


- **Mechanical laws**
  
  - Cortical: Elastoplastic (Johnson Cook)
  
  - Spongious: Elastoplastic with damage

- **Interfaces**
  
  - Node contacts
  
  - Line contacts
A numerical model of the shoulder

- Validation of the model

1. Isolated tests on bones
   - From literature
   - To fit accurately mechanical parameters
   - To valid each structure of the model

- Clavicle and Humerus

Three point bending tests on clavicle and humerus in static and dynamic conditions

Example of humerus test at 0.005 mm/ms

Force-displacement curves fitting with literature (Kirkish, 1996; Thollon, 2001)
2. Global test in lateral impact configuration

- Coupling with HUMOS finite element model
  - Thorax and upper extremity coupling
  - Material properties of thorax from HUMOS project
  - Integrate the stiffness and damping of each joint

- Simulation set up
  - Boundary conditions: Locking of T12 vertebra
  - Speed of impact: 4.5 mm/ms

- Validation of lateral impact
  - Mechanical behaviour from literature
  - Injuries from medical data register in lateral car crash
A numerical model of the shoulder

Introduction

Problem definition

Analysis

Anatomy
Development
Validation

Discussions

Conclusions

Acknowledgements

References

Good fitting with lesions observed in case of lateral car crash (Meyer, 1992) and medical dataset (Robinson, 1998)

Good fitting with literature and experimental tests (Bolte, 2004; Compigne, 2005)

Failure zone

Force (KN) vs. Time (ms)
A numerical model of the shoulder

Discussions

- Accurate/Precise and faithful model
  - Good bone biofidelity
  - Allow precise soft tissue insertion
  - Allow fracture propagation analysis

- Good results from validation test
  - Isolated test
    - Fracture description
    - Good curves fitting
  - Global test
    - Good curve fitting
    - Genesis of lesion :
      - Loading of humerus : 1st peak
      - Gliding into the joint : decreased phase
      - Loading of clavicle : 2nd peak
      - Failure of clavicle
    - Lesion according with medical dataset and experimental tests

Curve of global test
A numerical model of the shoulder

Further applications and perspectives

- Other impact configurations should be implemented
- Insertion of an approximated implant
- Strains and stresses values in shoulder during lateral loading
- Possible applications in kinematics analysis
A numerical model of the shoulder

Conclusions

A first step of this project is validated:

A complete model of shoulder bones

- Anatomy of model validated by orthopaedic physicians
- Mechanical behaviour validated
- Good injuries reproduction

Future improvements:

- More tests of validation
- Implementation of articular elements
- Addition of muscles and contractile properties
- Kinematics validation
- Insertion of actual shoulder prosthesis
A numerical model of the shoulder

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References


- Thollon L., « Modélisation du membre thoracique dans le cadre d’un choc latéral », PhD dissertation of biomechanics, Laboratoire de Biomécanique Appliquée, Université de la Méditerranée, 2001


