

# EXPERIMENTAL DETERMINATION OF PAIN AND INJURY LIMIT VALUES FOR HUMAN-ROBOT COLLISIONS

ERF 2015, Topic Group Industrial Robotics, Vienna

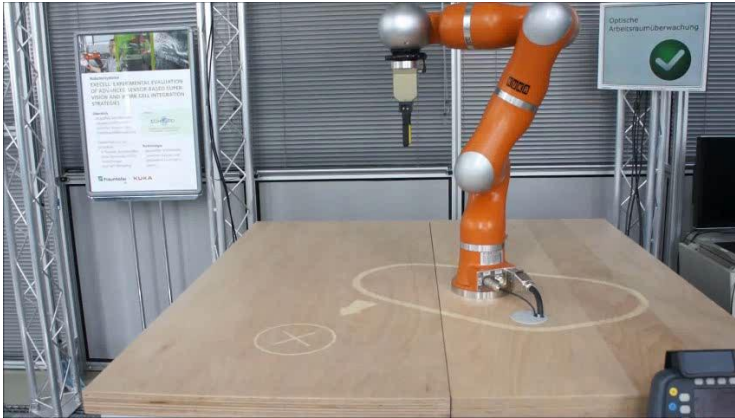
Dr. Norbert Elkmann

12<sup>th</sup> March 2015



# Assistance Robotics and Safe HRC

## Developments/Projects Fraunhofer IFF



Projection- and camera-based safety system for workspace monitoring with dynamic safety zones



Worker assistance with industrial robot handguided robot/ safety/ ergonomics



Tactile sensors for collision detection



Mobile assistant robot "ANNIE"

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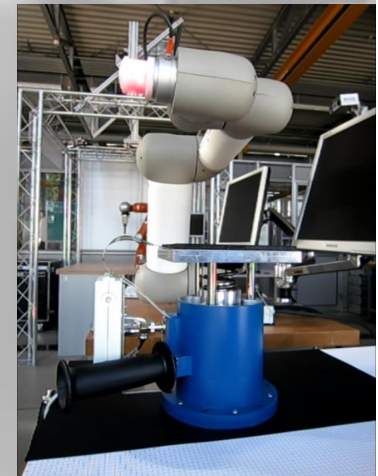
# Research on Human-Robot Collisions

## Projects at Fraunhofer IFF

- Determination of the influence of inertia on constrained and unconstrained human-robot collisions (clamping and free collisions (on behalf of the IFA))
- KAN-Study 52: Biomechanical force limits
- Examination of collision parameters with robots based on the Kolrobot measurement system (IFA)
- Experimental determination of *injury* onset for human-robot collisions (IFF and Medical Center University Magdeburg), since 2013
- Experimental determination of *pain* onset (IFF and Medical Center University Magdeburg), order by BGHM), planar static and dynamic contacting, since 12/2014



dynamic collision measurement system by Fraunhofer IFF



Examination of collision parameters with robots: Kolrobot measurement system (IFA)



# Experimental determination of biomechanical limit values in human-robot collisions

## Motivation, approach, aim

- Systematically identified limit values (pain and injury onset) for individual localizations
  - Determination of pain/injury-relevant input quantities (collision geometry, localization, velocity, mass, ...)
  - Evaluation of pain/injury related measurement quantities (force, pressure, impact, energy.....)
  - Aim: generation of pain onset and injury onset (moderate pain, swelling, bruise) data for relevant standards (esp. ISO/TS 15066)
- ➔ IFF approach: Collision experiments with volunteers

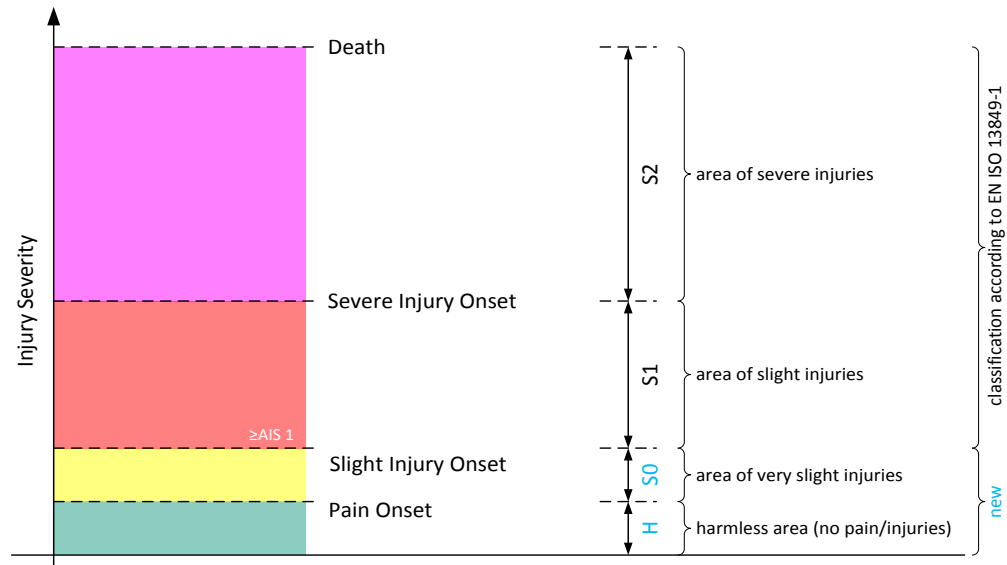


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# Experimental determination of biomechanical limit values in human-robot collisions

## New Severity Levels S0 (injury onset) and H (pain onset)

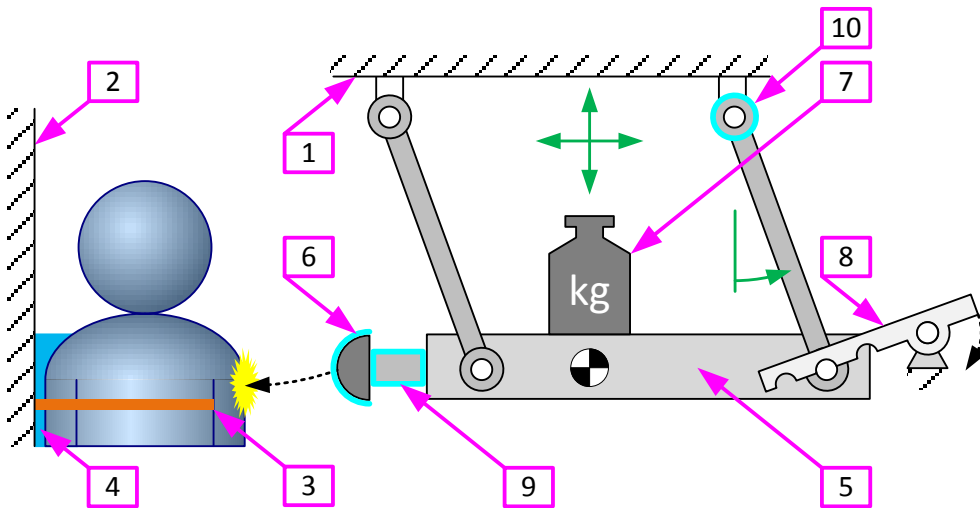
- Within the harmless area H no pain occurs during unintended contacts
  - For quasi-static contacts: Medical Center of the Johannes Gutenberg University Mainz (Germany)
  - For dynamic contacts: study by the Fraunhofer IFF



- The new severity level **S0** spans from the pain onset until the injury onset
- Injury onset is defined as
  - **Superficial injuries** (mild contusions) that heal without any consequences
  - **No skin opening**, no abrasion
  - The injury onset is defined by **moderate pain** or an **edema** (swelling, bump) or a **slight hematoma** (bruise)

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## Experimental set-up for dynamic collisions



- |                    |                                    |
|--------------------|------------------------------------|
| (1) Stiff Frame    | (6) Impactor incl. Pressure Sensor |
| (2) Stiff Rack     | (7) Additional Masses              |
| (3) Fixing Devices | (8) Locking Mechanism              |
| (4) Vacuum mat     | (9) Load Cell                      |
| (5) Ram            | (10) Precise Potentiometer         |



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# Experimental determination of biomechanical limit values in human-robot collisions

## Current studies, involved parties

### Fraunhofer IFF

- Initiator of the study
- Coordination and management
- Acquisition of volunteers
- Experimental design
- Execution of the experiment
- Result analysis

### University hospital of the Otto von Guericke University, Magdeburg

Institute for Forensic Medicine

Clinic for Dermatology & Venereology

Clinic for Trauma Surgery

Institute for Neuroradiology

Ethical approval from the ethical commission of the University Magdeburg

Study 1: Experimental determination of biomechanical limit values at human-robot collisions (IFF and Medical Center University Magdeburg), focus on *injury* onset S0  
Start 2013, in progress, supported by Daimler and KUKA

Study 2: Experimental determination of *pain* onset H (IFF and Medical Center University Magdeburg), planar static and dynamic contacting,  
Start: 12/2014, order by BGHM, Mainz, sub-contractor: University Mainz

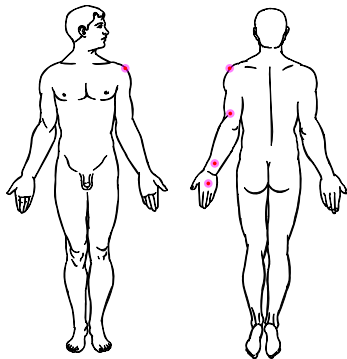
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# Experimental determination of biomechanical limit values in human-robot collisions

## Studies on biomechanical limit values

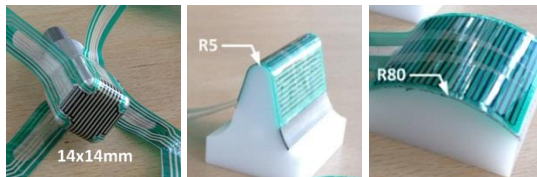
### IFF study on the injury onset

- 15 test subjects
- 4 localization
- Three different masses (5kg, 10kg and 15kg)



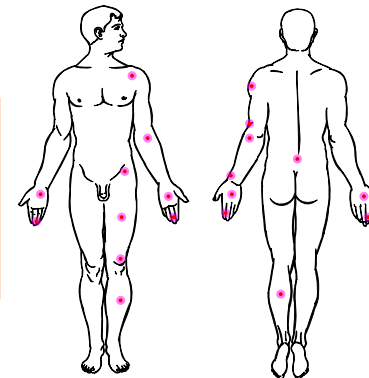
Target population:  
Men and women in  
an employable age  
(from 18 to 60)

- Three different impactors

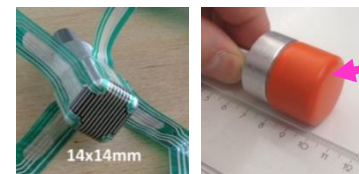


### IFF study on the pain onset

- 20 test subjects
- 21 localization
- Two different masses (5kg and 15kg)



- Two different impactors



Impactor with soft surface

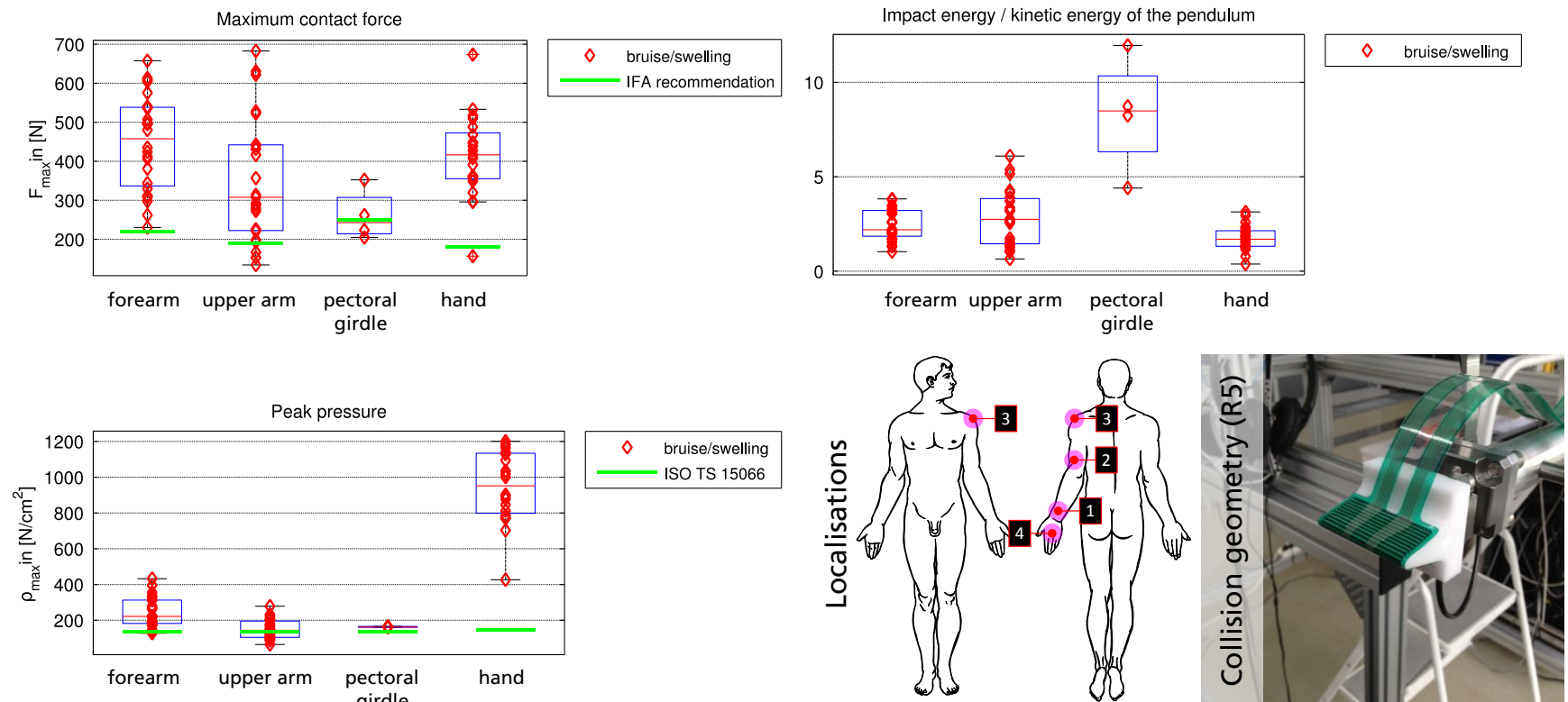
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# Experimental determination of biomechanical limit values in human-robot collisions

## Results: study „injury onset“

- Focus here: Maximum contact force, peak pressure, impact energy
- First phase of the study (7 test subjects) finished



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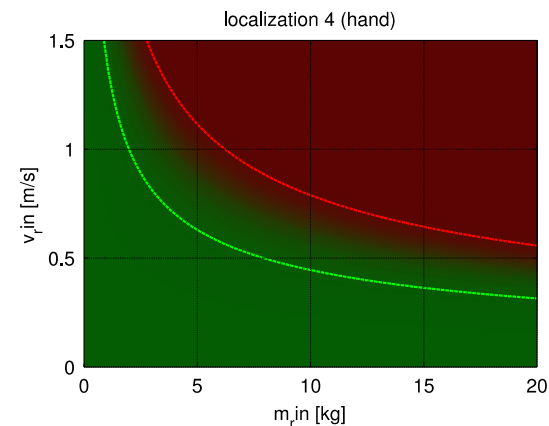
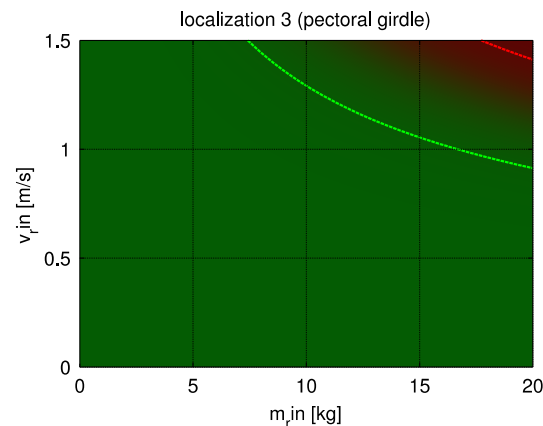
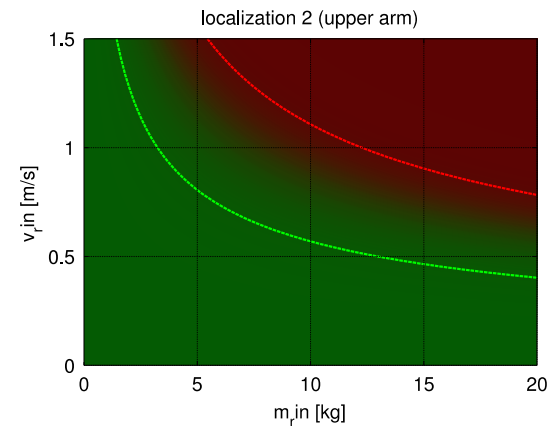
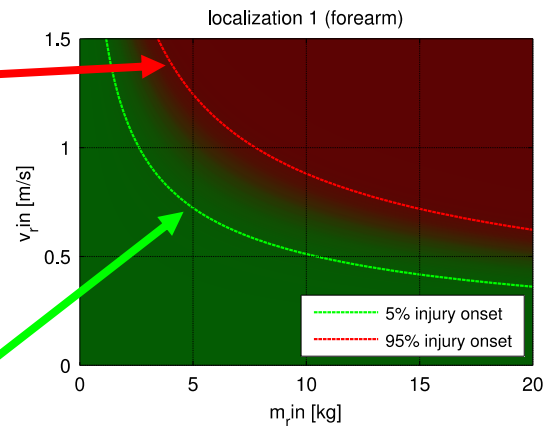
# Experimental determination of biomechanical limit values in human-robot collisions

Results: study „injury onset“, safety-diagrams (\*)

Above the red line the injury onset in appearance of a slight swelling or bruise is >95%

Below the green curve the injury onset in appearance of a slight swelling or bruise is <5%

Diagrams allow for programming safe robot motions



\*) K.T. Ulrich, T.T. Tuttle, J. P. Donoghue, W.T. Townsend, Intrinsically Safer Robots, Barrett Technology Inc., 1995

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# Experimental determination of biomechanical limit values in human-robot collisions

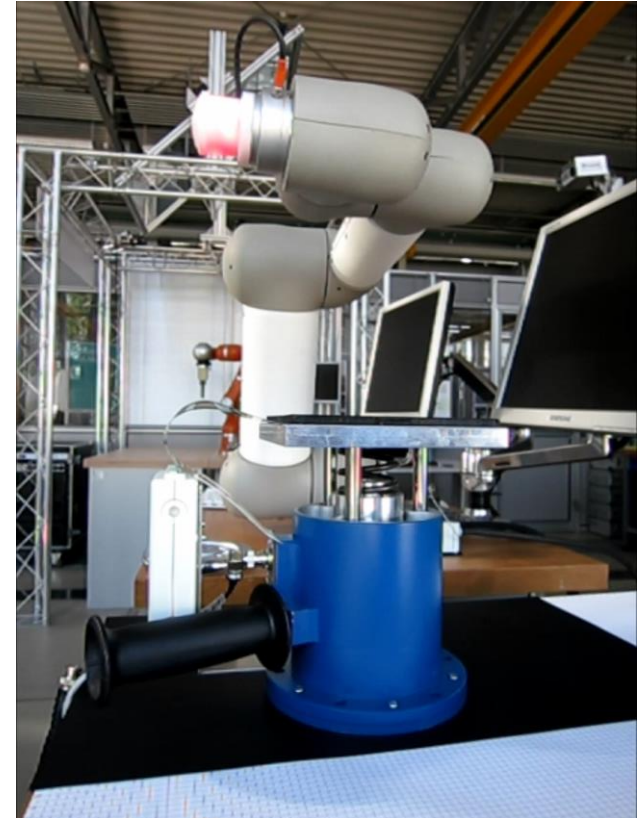
## Next steps

- Increase the recent data pool and results:
  - Continuing the study with further volunteers
  - Further body localizations that can be tested in this study
  - Examination of the pain and injury onset with more contact geometries
    - R80 impactor, BG impactor ....
- Comparison with the result from the pain onset study U Mainz
- Deriving industrially useful limit values from the experimental results in order to contribute the current standardization efforts (ISO TS 15066)
- Developing a suitable impact model that allows for the simulation of human-robot collisions with reliable results

# Experimental determination of biomechanical limit values in human-robot collisions

## Evaluation of robots for HRC

- Examination of robots regarding their dynamic collision and braking performances with measurement system Kolrobot by IFA (measurement of force and pressure)



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# EXPERIMENTAL DETERMINATION OF PAIN AND INJURY LIMIT VALUES FOR HUMAN- ROBOT COLLISIONS

Discussion

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# Current progress and latest results

## General experiences and observation

- Allowable velocity decreases with increasing robot masses as shown in the safety diagrams (effective inertia within impact point)
- Clear differences between the examined localization (shoulder is less fragile to blunt impacts than other arm regions)
- Anomalies at the pectoral girdle
  - Several times, none of the critical consequences were reached even when using the highest collision energy that can be applied with the current setup
  - The impulse is awkward in the region of neck and head (comparable with a slight whiplash)
- Anomalies at the hand
  - Neither bruising nor swelling occurs
  - Pressure peaks above 1200N/cm<sup>2</sup>
- More data needed!

# Experimental determination of limit values in human-robot collisions

## Current studies on biomechanical limit values at Fraunhofer IFF

### Determination of limit values...

IFF study on the onset of *injury*  
(financially supported by Daimler and KUKA)

- for the onset of *injury*
- for damage severity category S0 in case of *dynamic* contacts (collisions)

**Preliminary work:** IFF study on the onset of injury (1<sup>st</sup> phase)

- *Dynamic* contacts (collision)
- 7 test subjects, 4 localizations

IFF study on the onset of *pain*  
(by order of German BG)

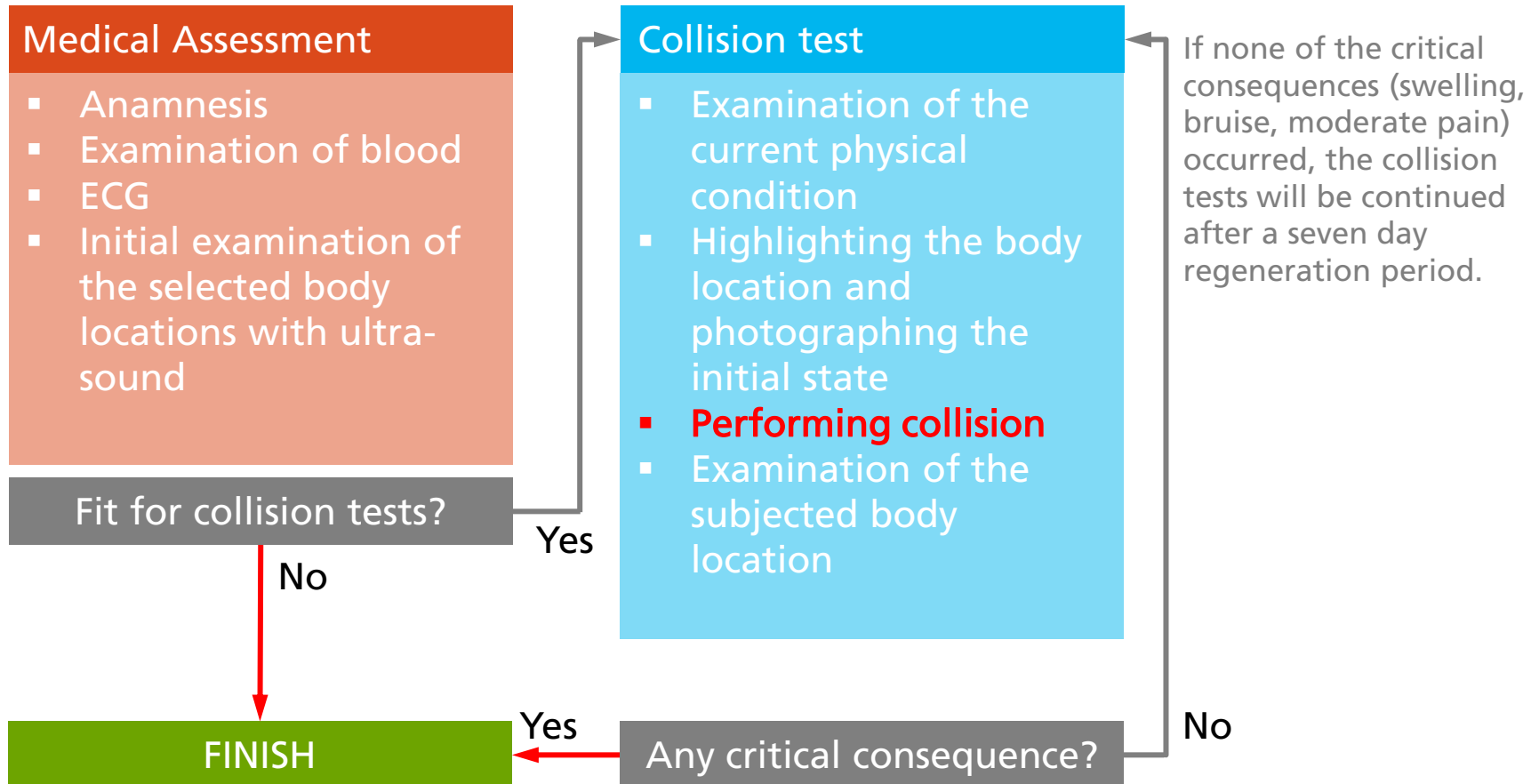
- for the onset of *pain*
- for damage severity category H in case of *dynamic* contacts (collisions)

**Preliminary work:** Study of the University of Mainz (funded by DGUV)

- *quasi-static* contacts (clamping)
- 100 test subjects, 29 localizations

# Experimental design

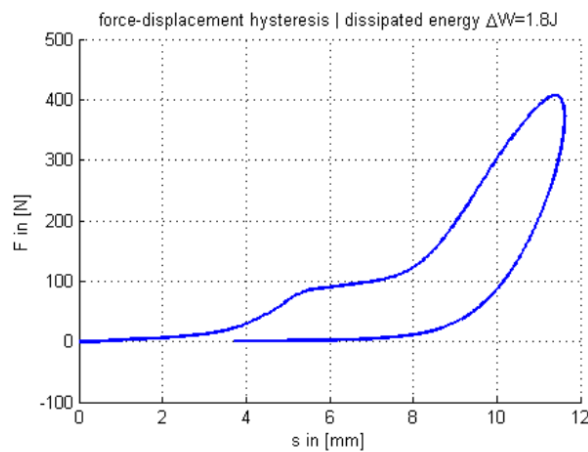
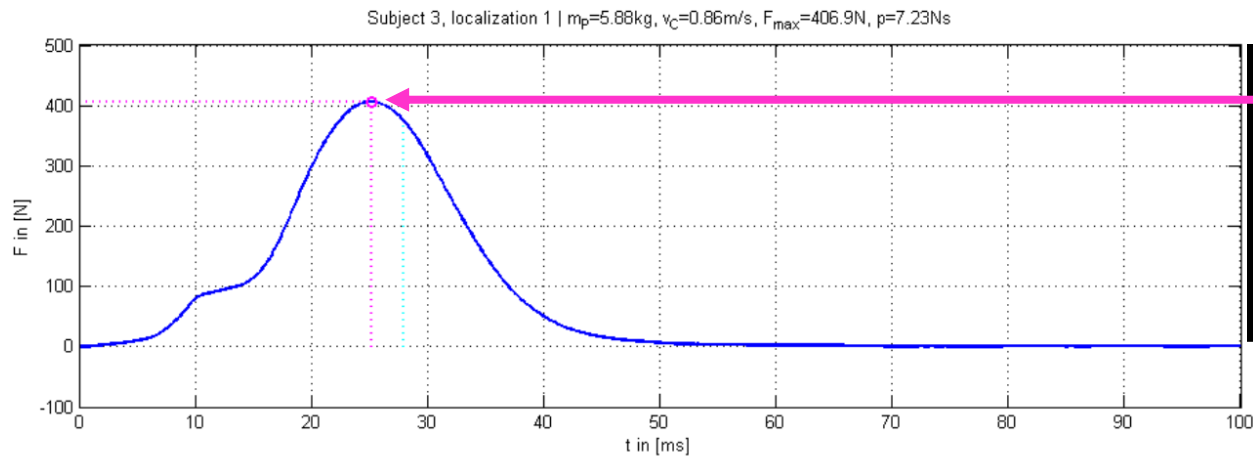
## Procedure for examining a specific localization



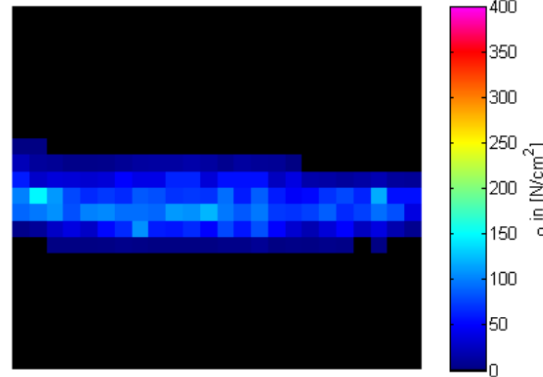


# Experimental procedure

## Analysis of the measurement (example: forearm)



peak pressure  $p_{\max}=147.2\text{N/cm}^2$  | peak power density  $\sigma_{\max}=66\text{W/cm}^2$



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