A Biomechanical Wrist Model for Patient-Specific Surgical Planning

JÖRG ESCHWEILER

Outline

- Introduction by the Host
- Main presentation “A Biomechanical Wrist Model for Patient-Specific Surgical Planning”
- Final words from the host
- Questions and answers

Dr.-Ing. Jörg Eschweiler

Kasper Pihl Rasmussen
(Host)

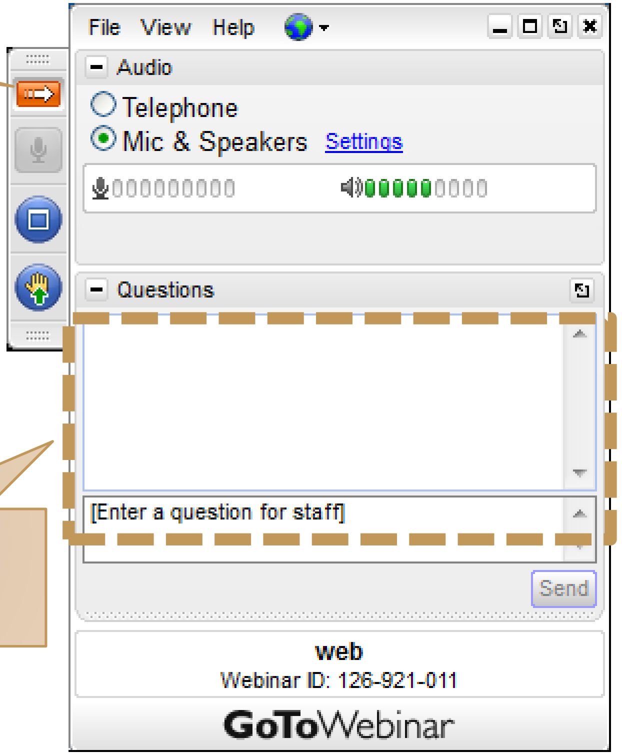
Control Panel

The Control Panel appears on the right side of your screen.

Submit questions and comments via the Questions panel.

> *Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.*

Expand/Collapse the Control Panel



○ Telephone
● Mic & Speakers Settings

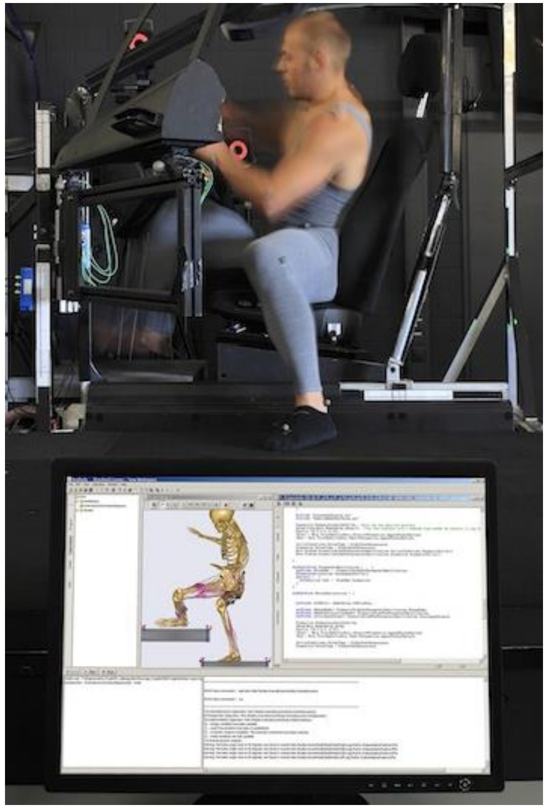
[Enter a question for staff]

Webinar ID: 126-921-011

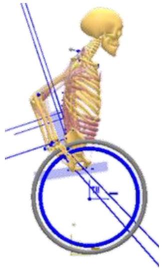
Ask a question during the presentation

AnyBody Modeling System

- Simulations of Musculoskeletal system
  - Internal loads during movement
- AnyBody Managed Model Repository
- Special simulations features
  - Reaction force prediction
  - Imaging → Patient-specific anatomy
  - Man-machine interaction simulations



Rasmussen et. al. (2011), ORS Annual Meeting

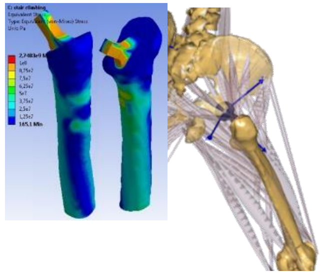


Product Design Optimization

Movement Analysis

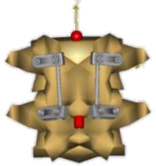
Ergonomic Analysis

ANYBODY Modeling System

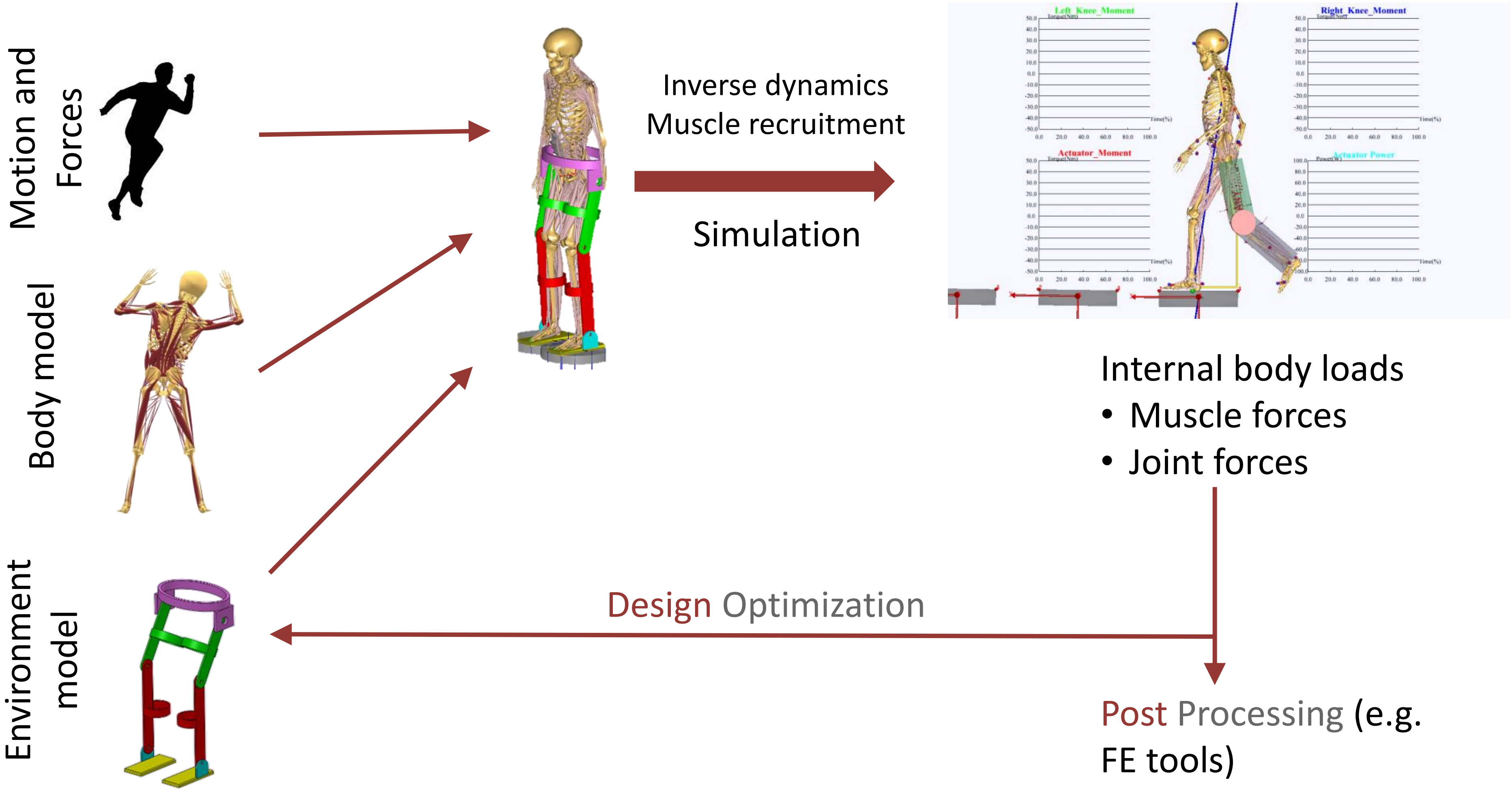


Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation



AnyBody Modelling System



Motion and Forces

Body model

Environment model

Inverse dynamics
Muscle recruitment

Simulation

Internal body loads
- Muscle forces
- Joint forces

Design Optimization

Post Processing (e.g. FE tools)

A Biomechanical Wrist Model for Patient-Specific Surgical Planning

JÖRG ESCHWEILER

Development of a biomechanical model of the wrist joint for patient-specific model guided surgical therapy planning

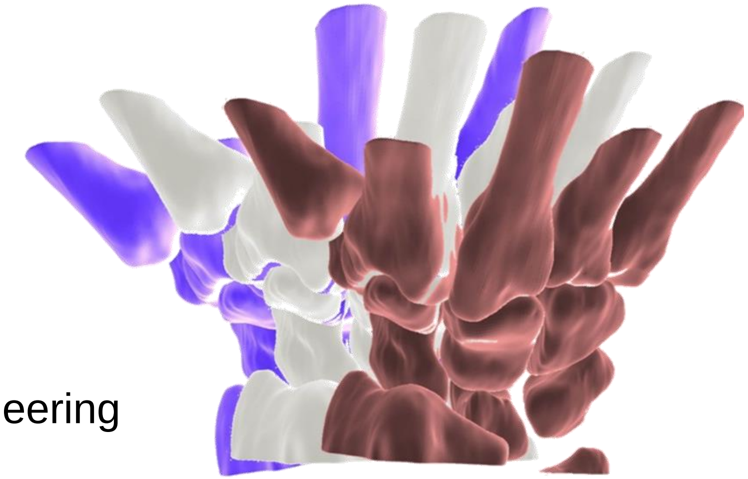
Jörg Eschweiler, PhD (eschweiler@hia.rwth-aachen.de)

Maximilian M. C. Fischer, Dipl.-Ing.

Klaus Radermacher, PhD

Chair of Medical Engineering

Helmholtz-Institute for Biomedical Engineering
RWTH Aachen University, Germany
http://www.meditec.hia.rwth-aachen.de



Team “Biomechanical Modelling and Simulation”

Chair of
Medical Engineering at
Helmholtz-Institute for
Biomedical Engineering

Modelling of apriori knowledge on morphology and function is of major importance for an efficient therapy planning. Supplemented and individualized on the basis of image-data and functional information, it allows the physician **to simulate** surgical interventions and their consequences and thus to develop and implement therapy-concepts adapted to patient-specific needs.

Between the Department of Orthopaedics and the research group of Biomechanical Modeling and Simulation, the **Working Group on Clinical and Experimental Orthopaedic Biomechanics** has been established. Valuable synergy effects can be achieved by the close cooperation with the area of "Clinical and Experimental Orthopaedics", led by Priv.-Doz. Dr. med. Björn Rath.


Dr.-Ing. J. Eschweiler (team leader)


Dipl.-Ing. (Syr.) G. Al Hares


W. Alrawashdeh, M.A.


Dipl.-Ing. M. Asseln

Dipl.-Ing. M. Fischer


Dipl.-Ing. C. Goffin


A. Holterhoff, M.Sc.


Univ.-Prof. Dr.-Ing. K. Radermacher


N. Siroros, M.Eng.


M. Verjans, M.Sc.

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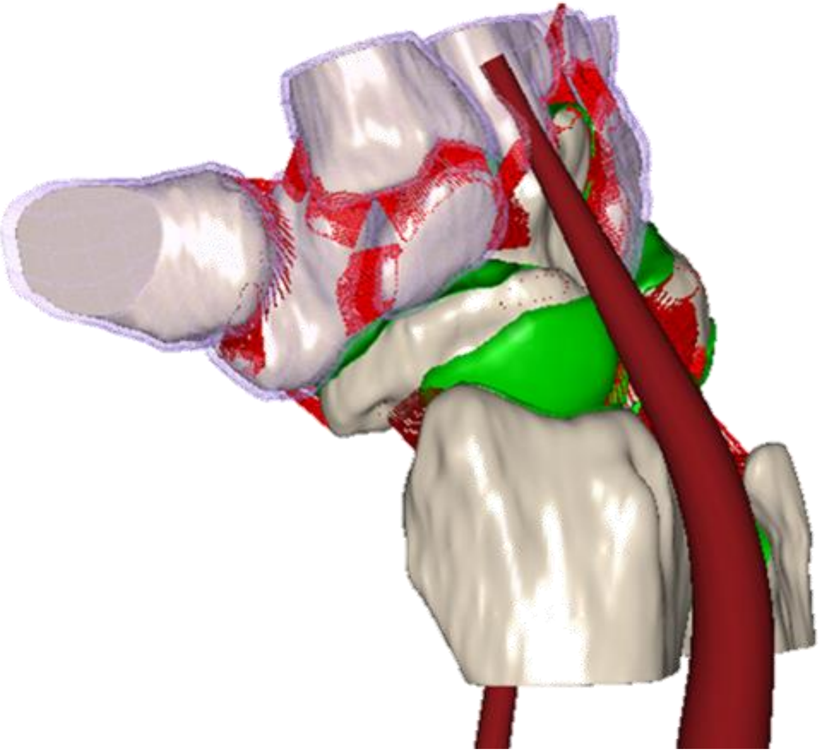

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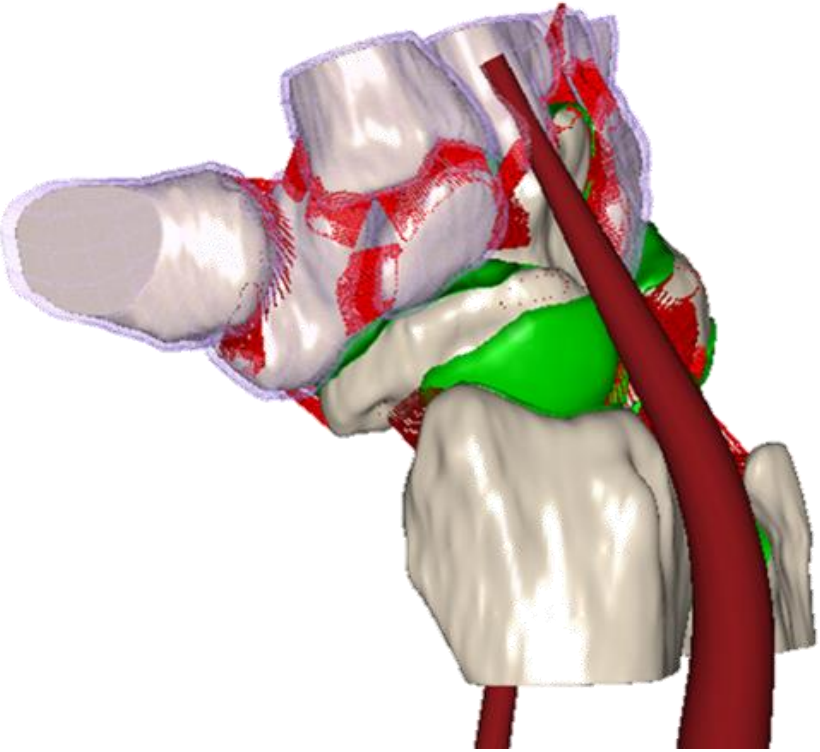


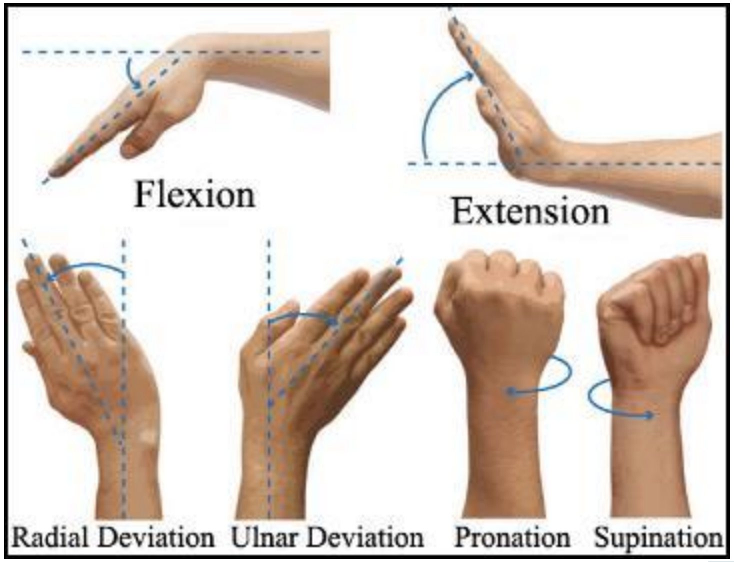
Introduction

www.youtube.com

- wrist is a complex joint
- a collection of multiple bones and joints
- multiple general motions

Adequately diagnose and treat carpal injuries:

- important to understand the basic science/ clinical relevance of wrist kinematics [Rainbow 2015]
- This is defined as motions necessary to carry out high-demand activities of daily living.



http://morphopedics.wikidot.com/radiocarpal-joint

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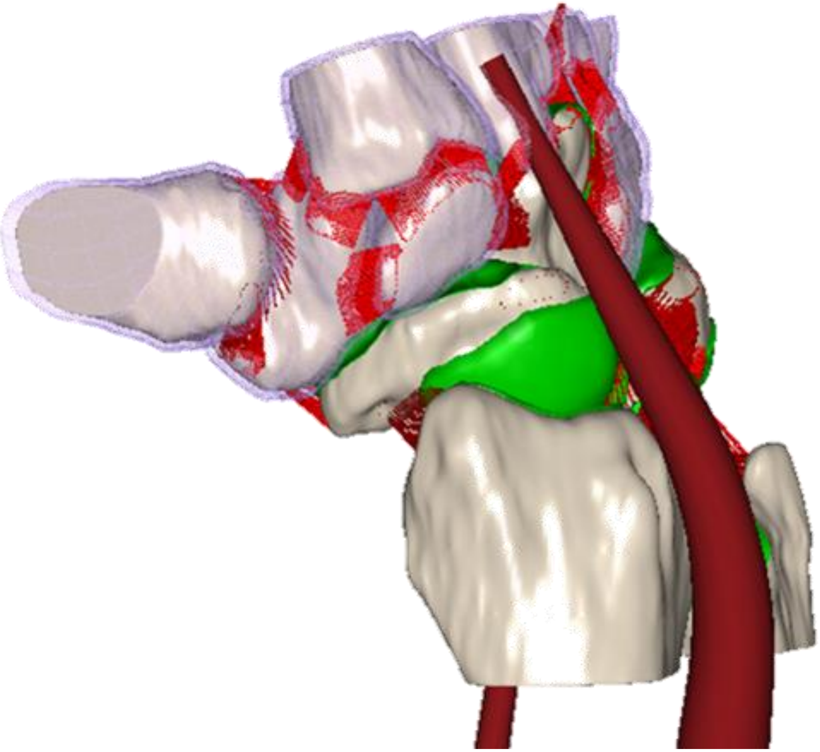
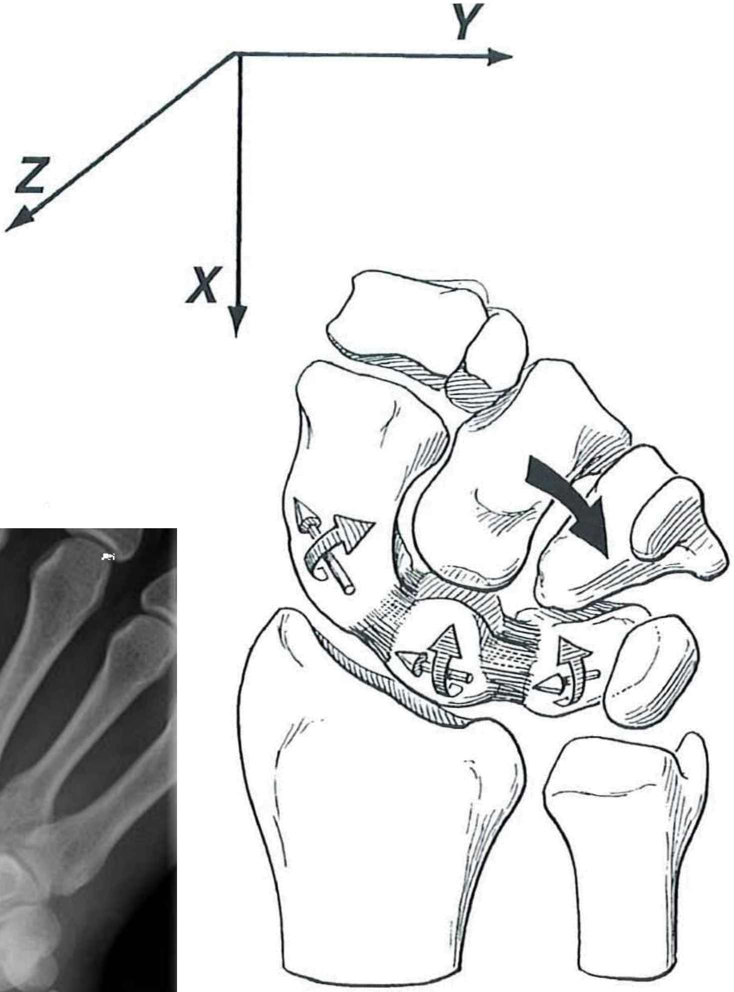


Anatomy of the wrist joint

- **The carpus:**
  - complicated set of interactions between the five metacarpals, eight carpal bones (= the carpus), and the radius and ulna [Rainbow 2015]
  - “bridges” the hand to the forearm
  - transmit load between the hand and the forearm



[Cooney 2011 – The Wrist, p. 98]

Anatomy of the wrist joint

The carpus is organized

into 2 groups:

A proximal row and a distal row

- **Proximal row (green)includes:**
  - scaphoid
  - lunate
  - triquetrum
  - pisiform
  - intercalated segment
- **Distal row (blue) includes:**
  - trapezium
  - trapezoid
  - capitate
  - hamate

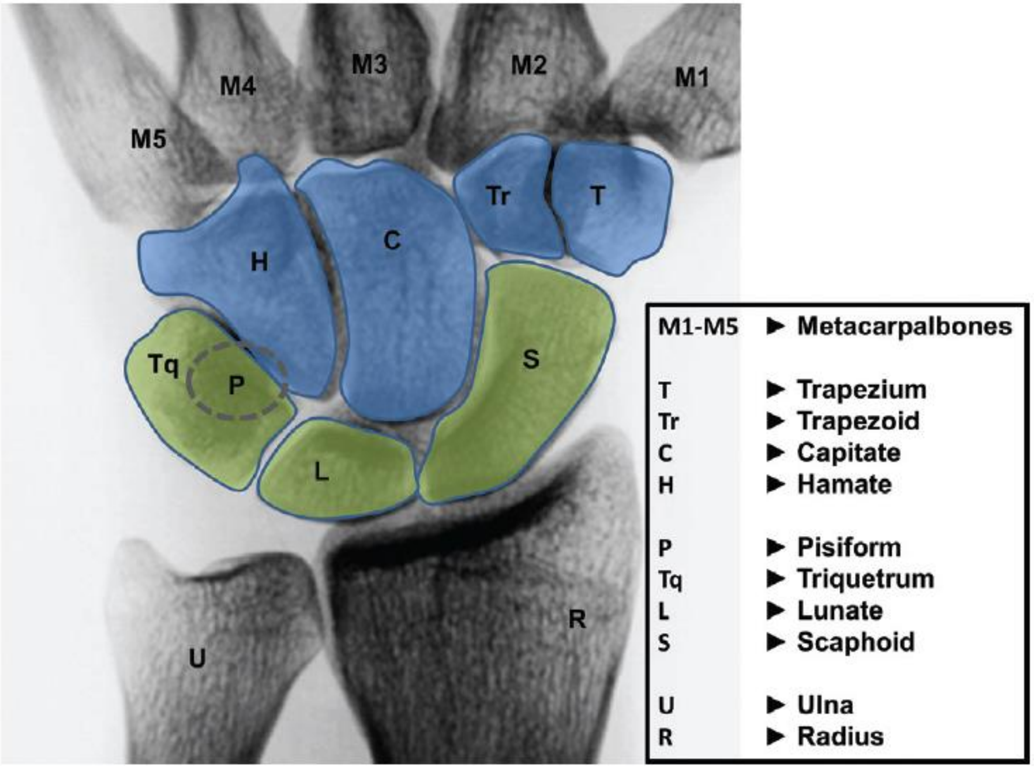


Figure 1: Palmar view of the wrist joint; the pisiform bone is implied as a dotted line. The green marked bones are included in the proximal row. The blue marked bones define the distal carpal row.

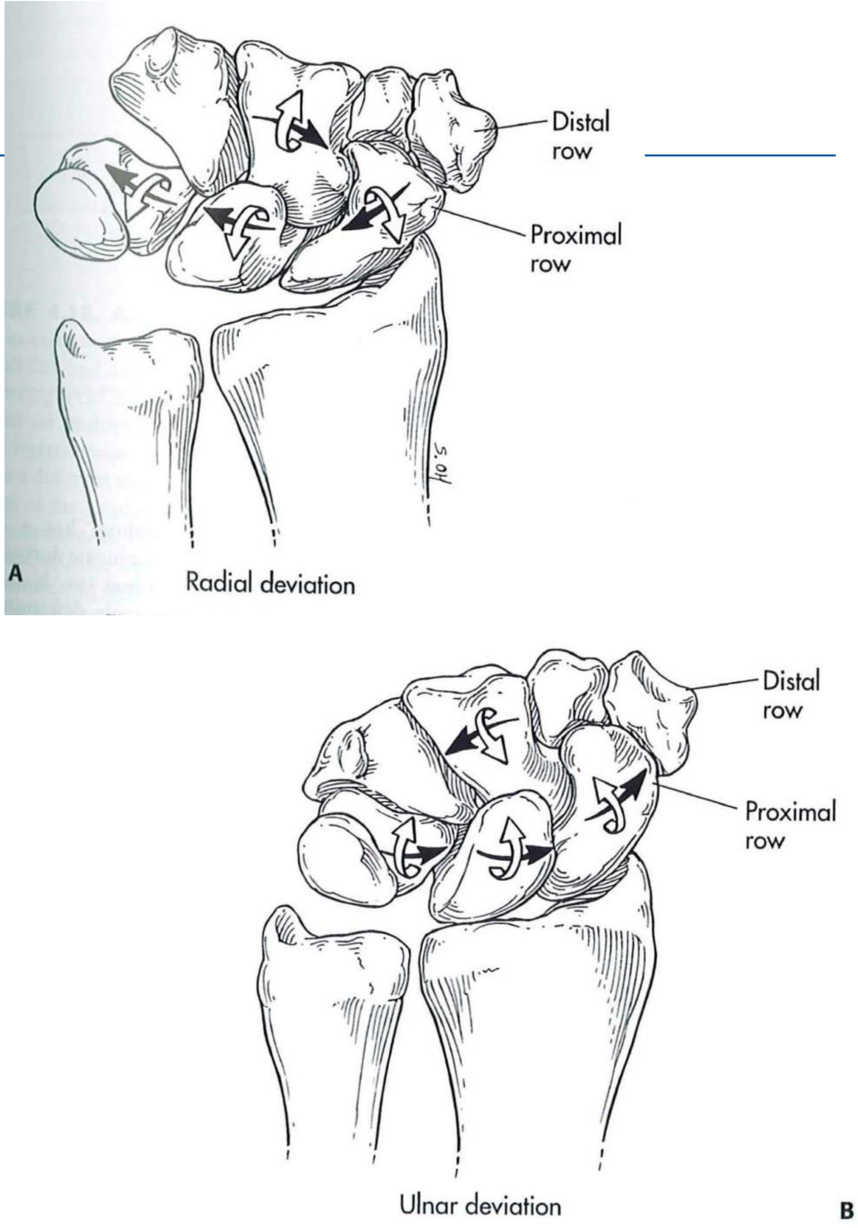
[Eschweiler 2016a]

Anatomy of the wrist joint

- **All of these bones**
  - participate in complex articulations
  - allow variable mobility of the hand

- **Proximal Row**
  - loose fit
  - scaphoid and lunate form most of articulation with the radius
  - variable geometry to accommodate movements

- **Distal Row**
  - tight fit
  - only minimal movement between distal row and metacarpal bones

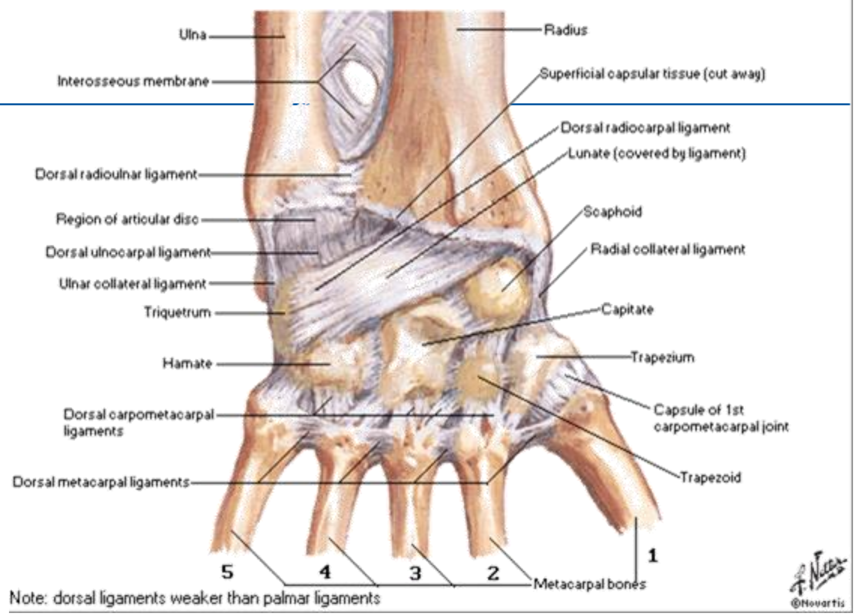


[Cooney 2005 – The Wrist, p. 89]

Anatomy of the wrist joint

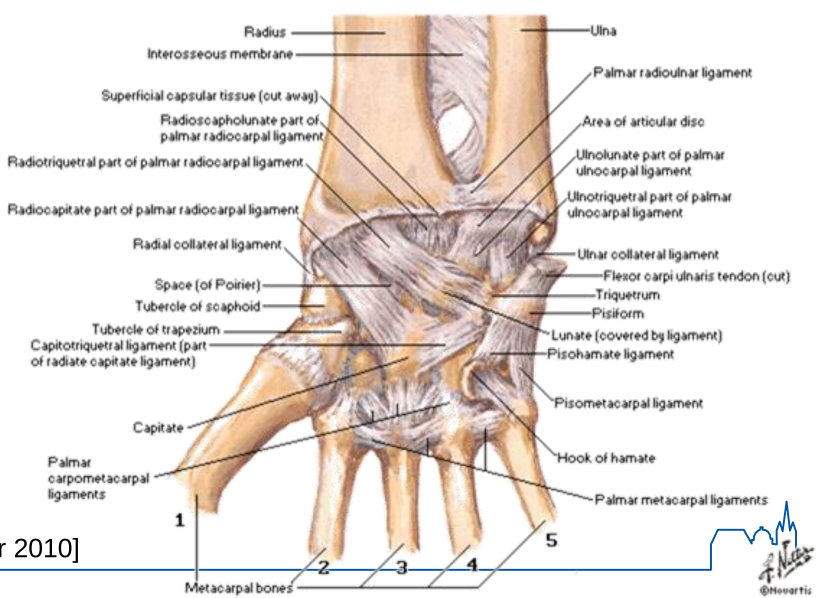
- **Complex ligamentous apparatus**
  - Extrinsic (or capsular) ligaments
  - Intrinsic (or interosseous) Ligaments
- **Disruption of this system**
  - leads to changes in individual carpal bone motion
  - leads to an abnormal load transmission (collectively termed carpal instability)
  - leads to pain and loss of function

Posterior [Dorsal] View



Note: dorsal ligaments weaker than palmar ligaments

Flexor Retinaculum Removed - Palmar View



[Netter 2010]

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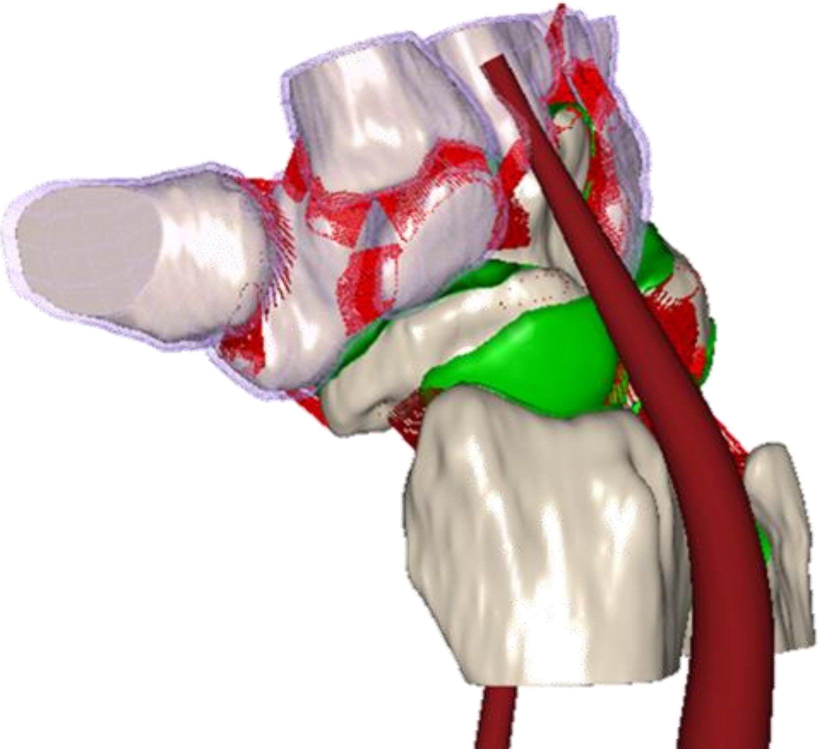
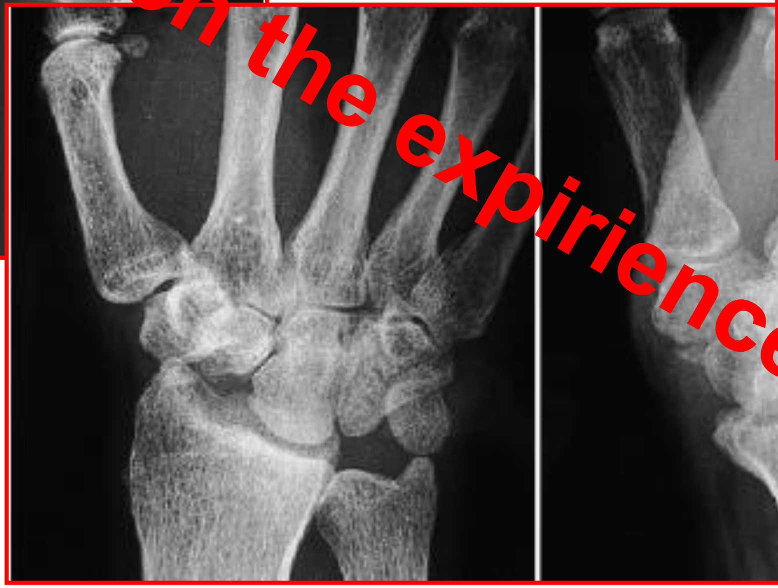


Clinical background

Therapy based on the expirience of the surgeon

Complete arthrodesis

Endoprosthesis



Removing the proximal carpal bones

[Meier 2002; Bultmann 2005; Lautenbach 2003]

Clinical background

- Hand and wrist injuries in Germany generally:
  - ⇒ In most of the statistics: No differentiation between hand and wrist (joint) injuries
  - ⇒ Difficult to find reliable data explicit for wrist and wrist joint injuries

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  - o 120,482 hand and wrist interventions per anno [Statistisches Bundesamt 2010]
  - o Furthermore, 325,418 accidents at work with hand and wirst involvement (35% of all accidents at work) (Statistic of the Deutschen Gesetzlichen Unfallversicherung (DGUV))
  - o For 2011: 179.0 loss days of work per 1000 insured male individuals, 51.5 loss days of work per 1000 insured female individuals [BKK 2011]
  - o Hand and wrist involvement in sport accidents: 11 up to 15% [Gläser 2001, Brüser 2011]
  - o Error in treatment: 41.7% of all hand surgical interventions (2004-2008, n=446 cases) [Brüser 2011]

Clinical background

- Wrist injuries in Germany specifically:
  - 7% of work accidents are specially wrist and wrist joint injuries (66,061 cases) [Zuther 2009]
  - Clinical procedures 2011 without work accidents: 62,429 injuries of the wrist joint (2010: 58,616) [Statistische Bundesamt 2013]

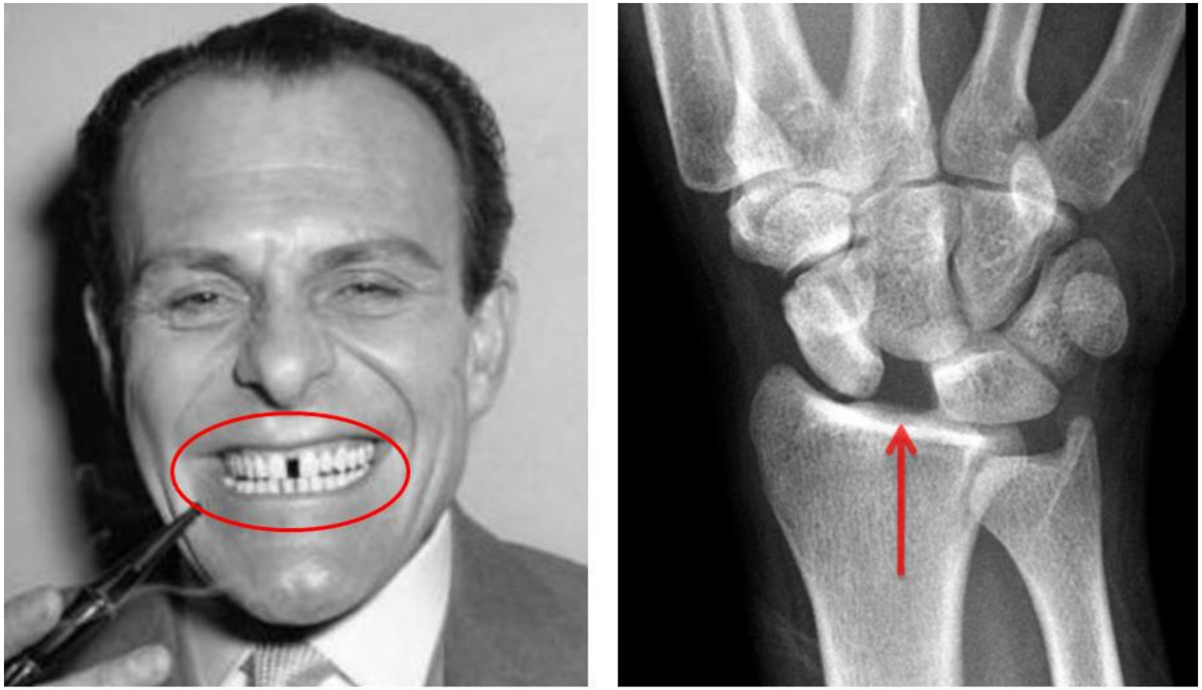
    ⇒For example: Increasing trend of wrist ligament ruptures=> 2000: 934 cases of wrist ligament ruptures, and in 2011: 2,267 cases [Statistische Bundesamt 2013]
  - 15 up to 25% of all forearm fractures are distal radius fractures and most of them with involvement of the wrist joint [Hartel 1987, Schädel-Höpfner 2008] (Incidence: 220 – 480 cases / 100,000 inhabitants)

  - Furthermore, the implantation of a wrist joint prosthesis is not an established surgical procedure. [Lautenbach 2003, Daecke 2005, Rehart 2003]

=> The durability of a wirst joint prosthesis is less than 5 years. [Lautenbach 2003]

Clinical background

- One of the most common pathways to carpal instability is disruption of the scapholunate ligament. [Rainbow 2015]
- This leads to an inevitable and progressive deterioration of wrist function (scapholunate advanced collapse (SLAC)) through the disruption of normal proximal carpal row mechanics. [Rainbow 2015]



Terry Thomas sign => SL-gap > 3mm

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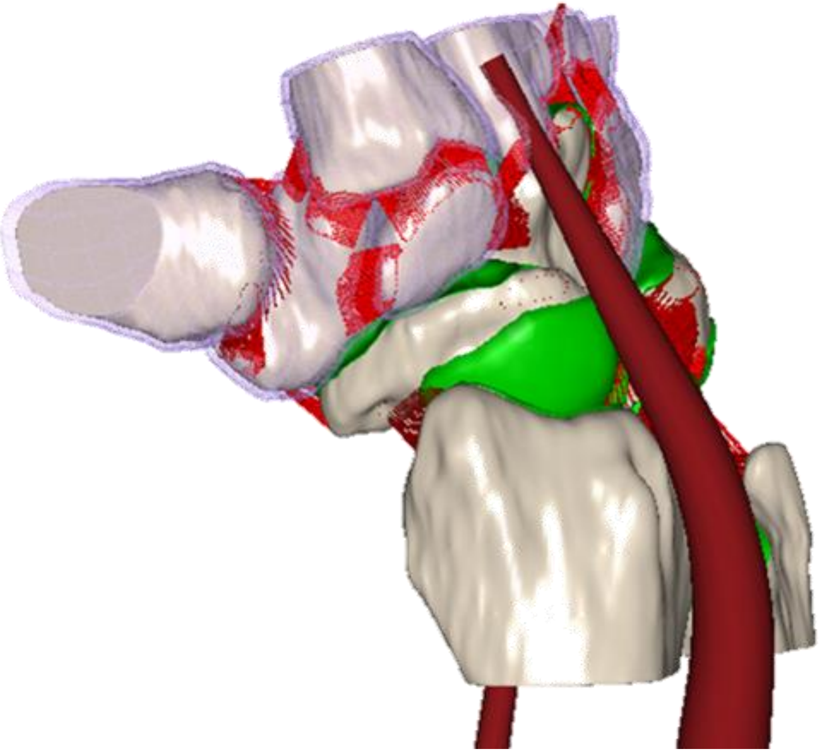
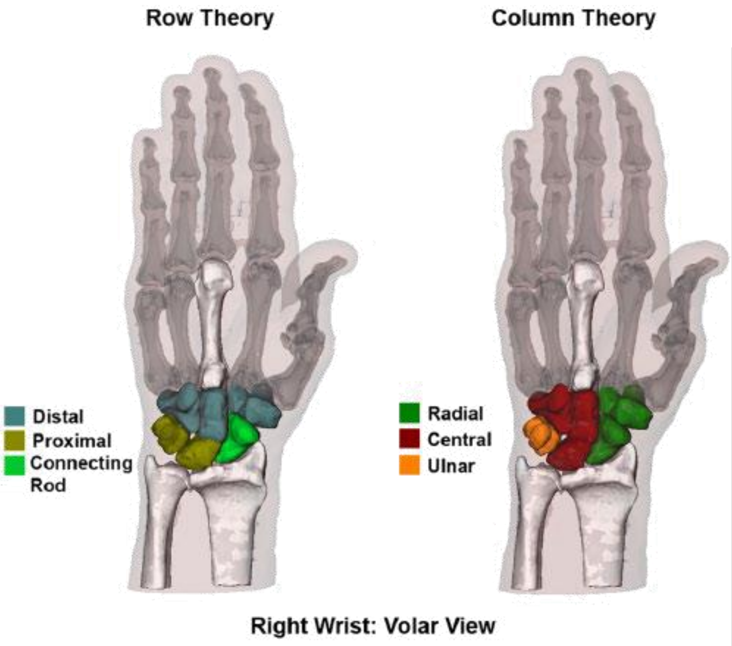
    3. Simulation Setup
6. Results
7. Discussion
8. Conclusion and Future Work



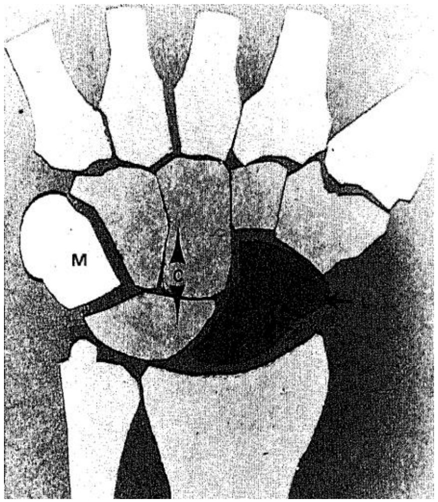
State of the art in wrist joint modelling

- **Conceptionel models**
  - Descriptive models of the wrist to explain kinematic behaviour and joint stability
    - Row Theory (from an anatomical point of view) [Bryce 1899, Destot 1926]
    - Column Theory [Navarro 1921]
    - Row-Column-Theory [Taleisnik 1976]
    - Ring-Theory [Lichtman 1981]



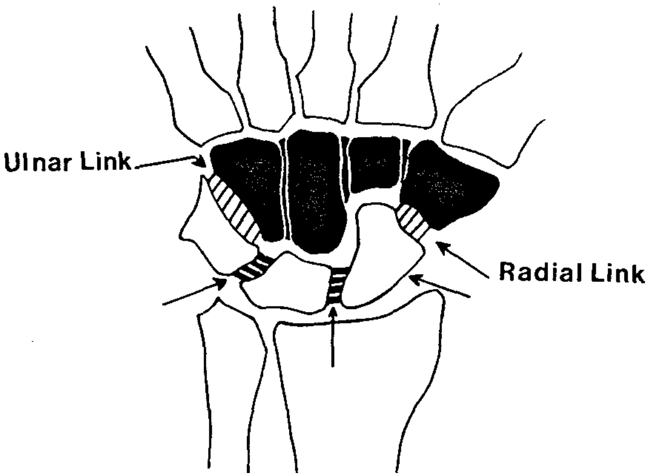
[Rainbow 2015]

Row-column-model



[Taleisnik 1976]

Ring-model

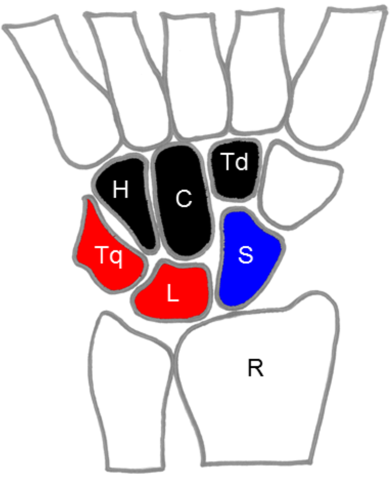


[Lichtman 1981]

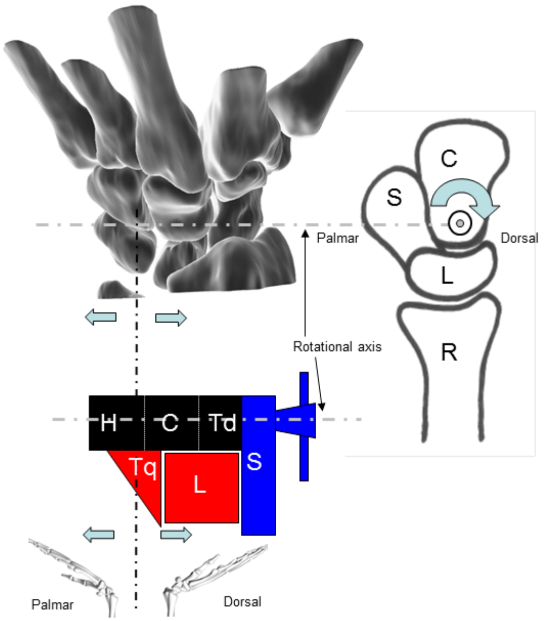
State of the art in wrist joint modelling

- **Conceptionel models**
  - Descriptive models of the wrist to explain kinematic behaviour and joint stability
    - Screw clamp Theory [MacConaill 1941]
    - Link joint Theory [Gilford 1943]

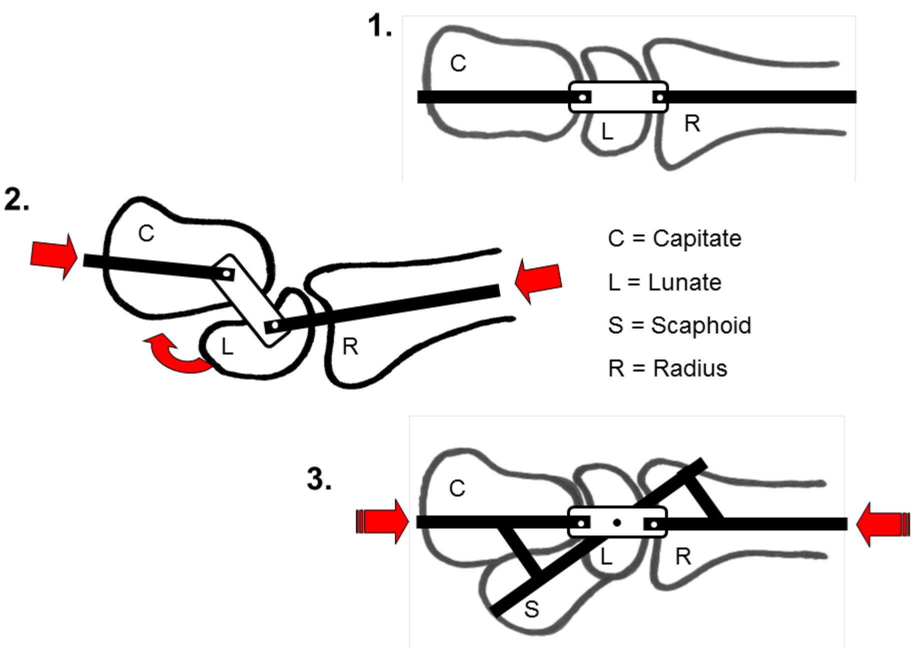
A: Carpal bone grouping



B: The „Screw clamp“



Link joint theory

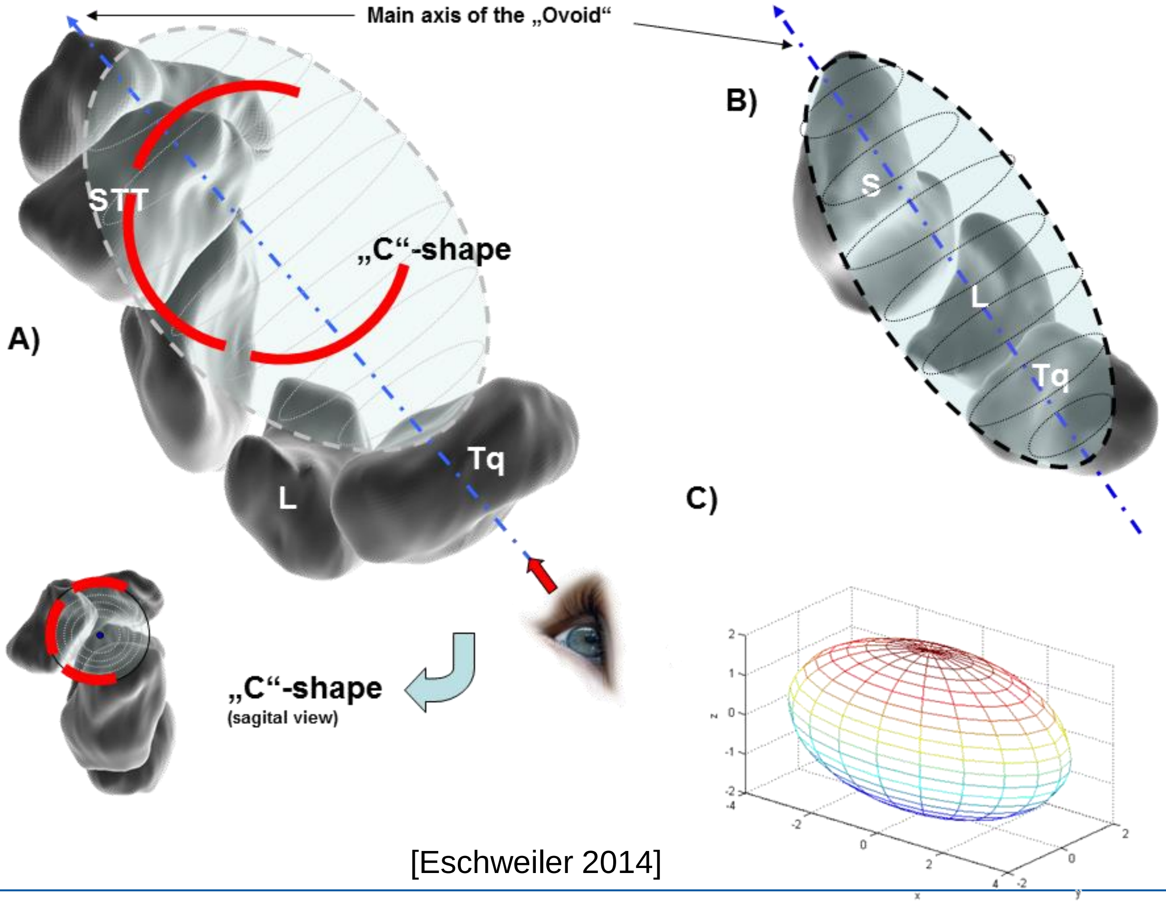


C = Capitate
L = Lunate
S = Scaphoid
R = Radius

[Eschweiler 2014]

State of the art in wrist joint modelling

- **Conceptionel models**
  - Descriptive models of the wrist to explain kinematic behaviour and joint stability
    - Ovoid – C-shape Theory [Moritomo 2006]

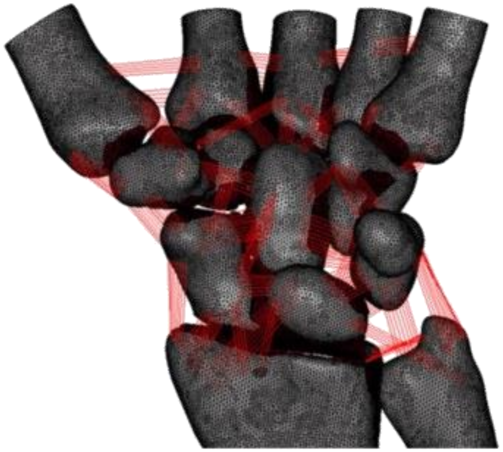


[Eschweiler 2014]

State of the art in wrist joint modelling

- **Computer models**
  - **Rigid Body Spring (RBS) models** [Kılıç 2007, Fischli 2009, Majors 2010]
    - investigation of wrist joint kinematic with non deformable rigid bodies
  - **Finite Elemente (FE) Models** [Carrigan 2003, Gislason 2009, Bajuri 2012]
    - investigation of cartilage and bony deformation in static positions

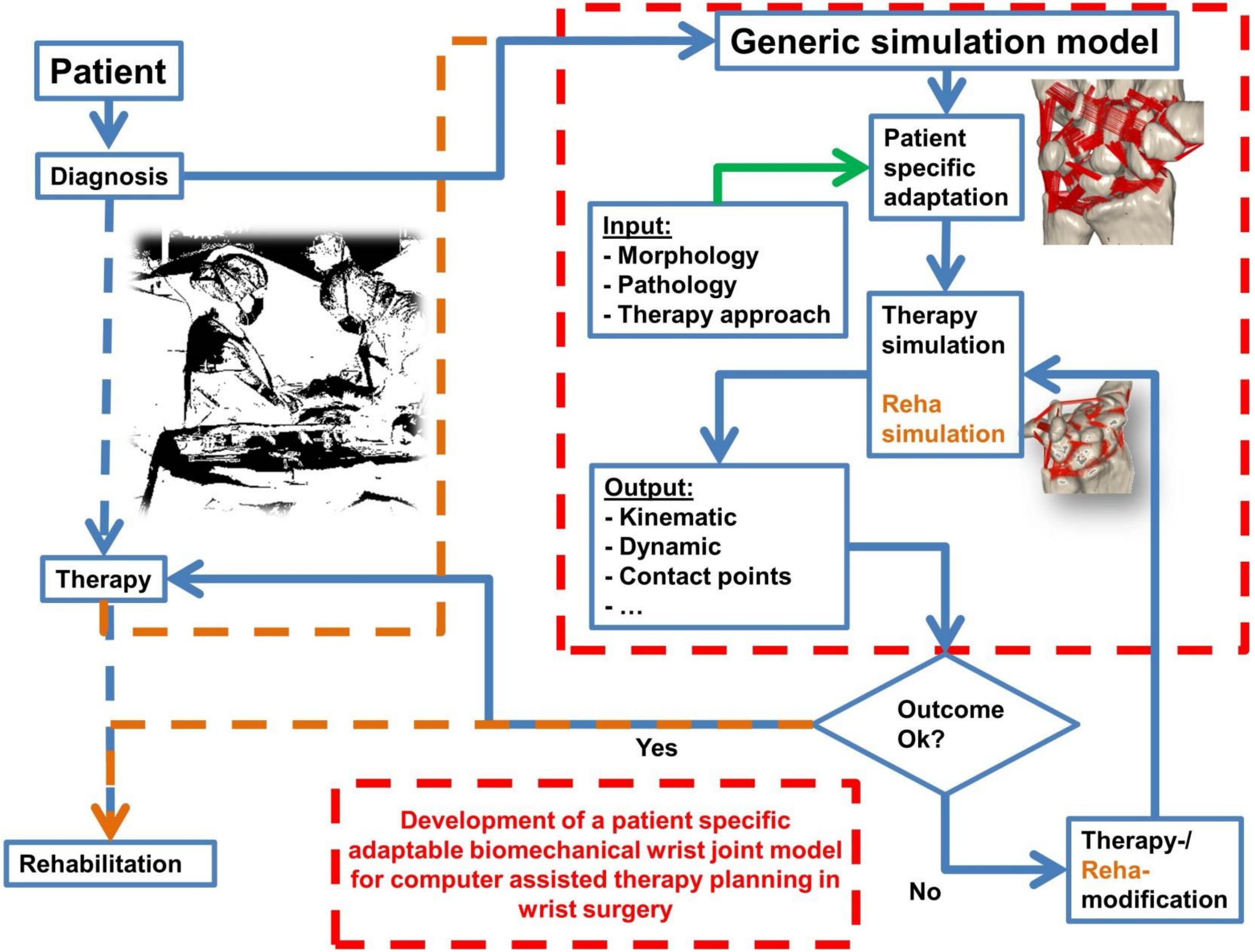
[Fischli 2009]



[Bajuri 2012]

Presently:
- **no existing model for therapy planning**
- **no existing patient specific adaptable model**
- **no existing valid model**

Motivation



Patient

Diagnosis

Therapy

Rehabilitation

Generic simulation model

Patient specific adaptation

Input:
- Morphology
- Pathology
- Therapy approach

Therapy simulation

Reha simulation

Output:
- Kinematic
- Dynamic
- Contact points
- …

Outcome Ok?

Yes

No

Therapy-/ Reha- modification

Development of a patient specific adaptable biomechanical wrist joint model for computer assisted therapy planning in wrist surgery

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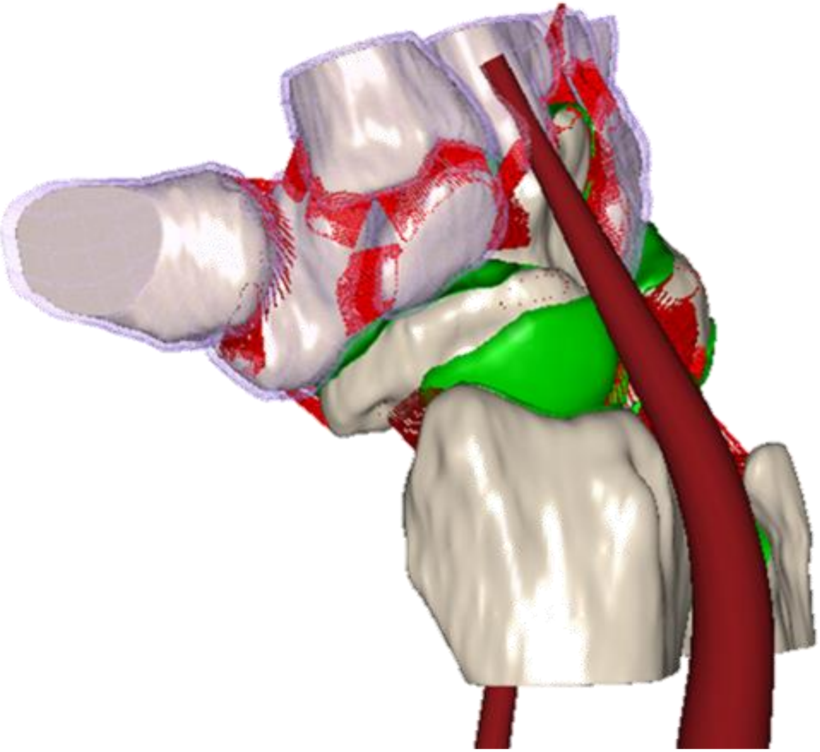
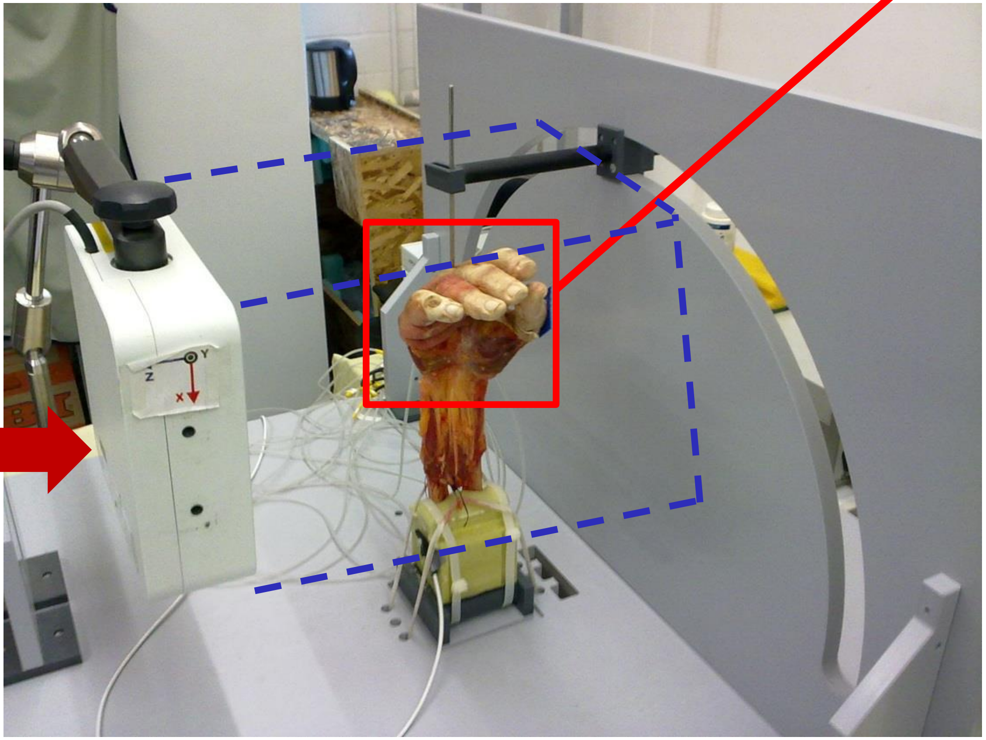


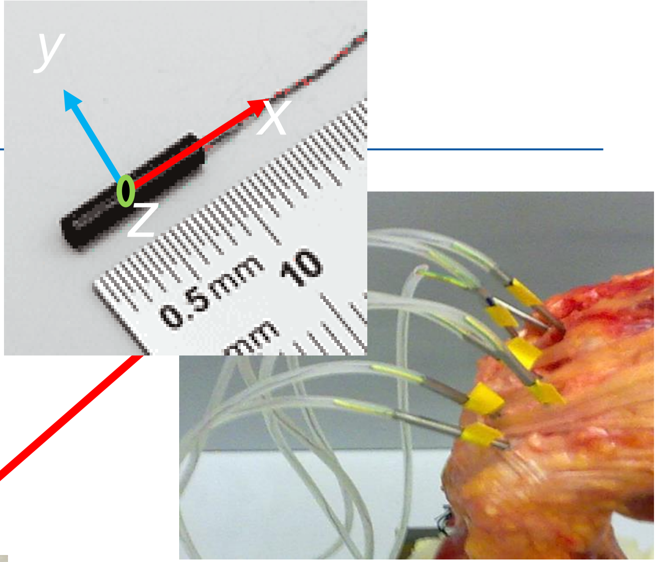
Material and Methods – Experimental setup

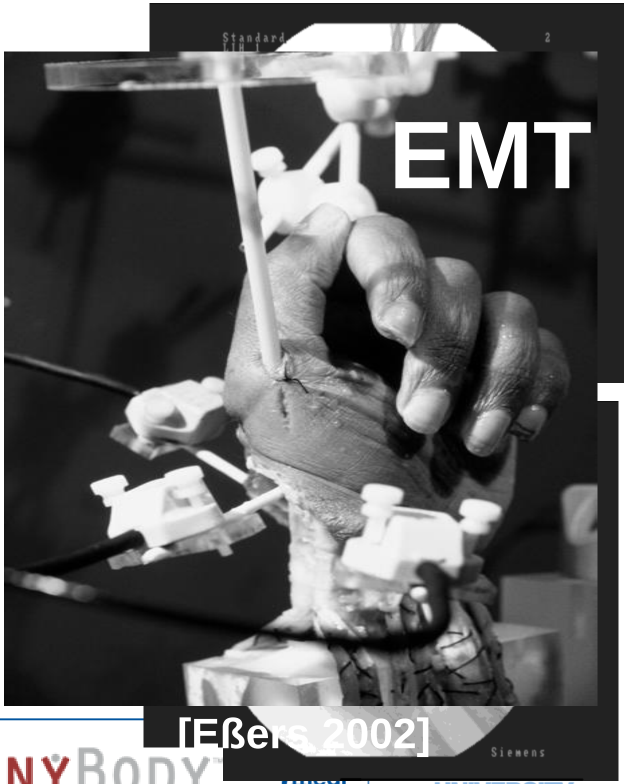
- **Motion simulator with EM-Tracking**
  - Flexion/ extension
    - In plane motion
  - Circumduction
    - Free motion, physiological constraints
  - Radial-/ Ulnarduction
    - In plane motion

Electro-Magnetical-Tracking (EMT) System

⇒ Accuracy:
0.5 mm
and
0.5°



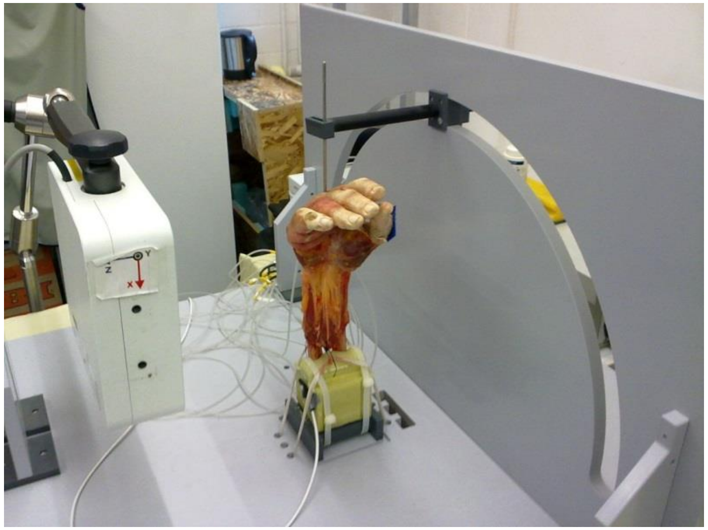


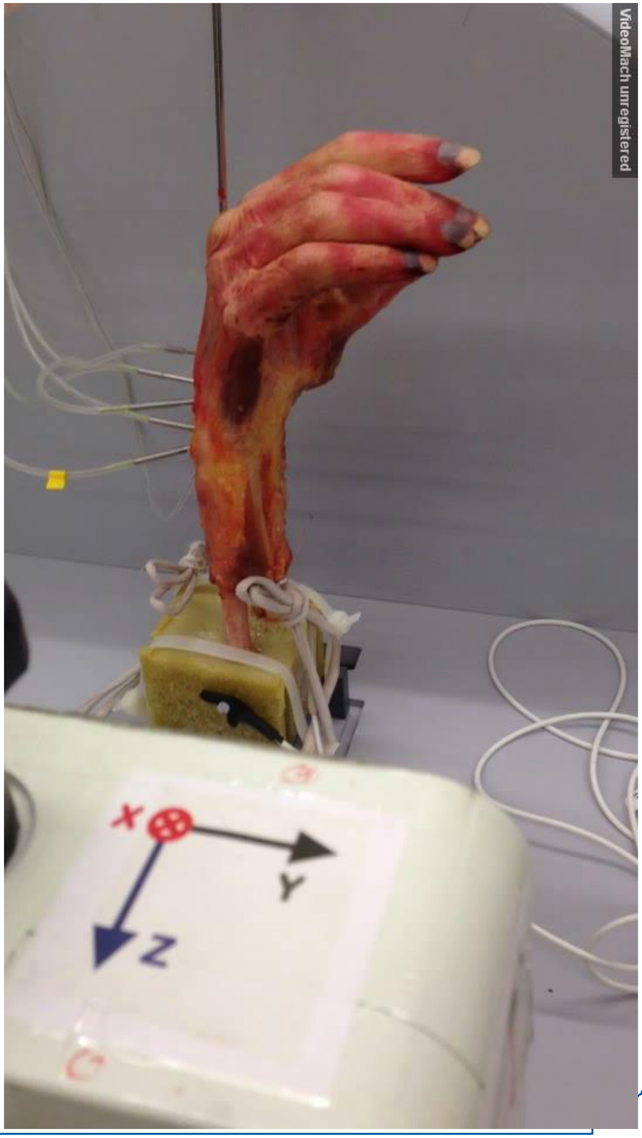


[Eßers 2002]

Material and Methods – Experimental setup

- **Passive motion**
  - Example: Neutral position to full flexion position and back to full extension
  - Steinmanpin (connection to motion simulator)
    - implanted in the third metacarpal bone
    - guided in a long hole (in plane motion)
  - No additional forces were applied from outside





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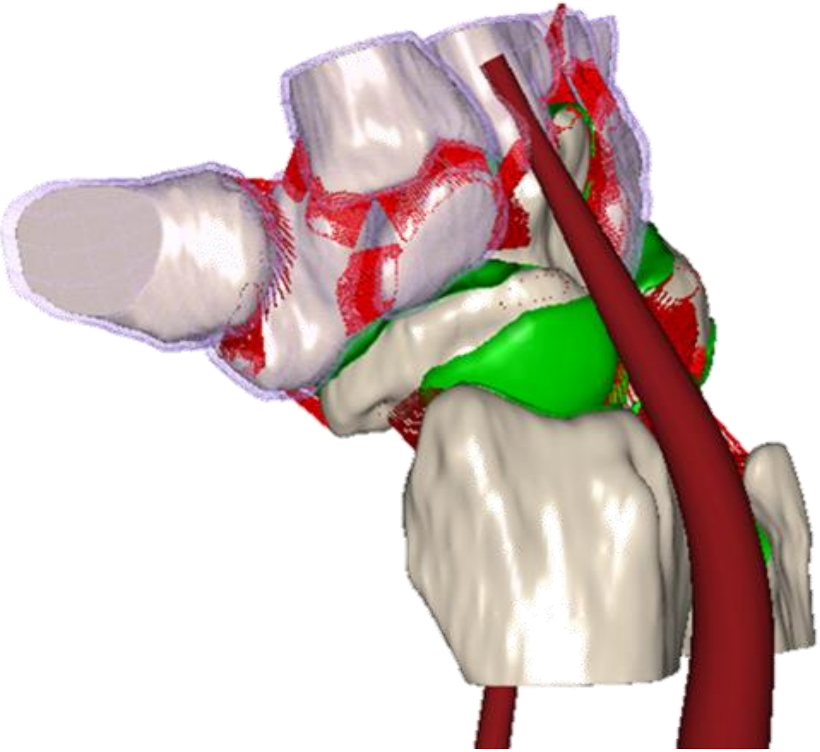
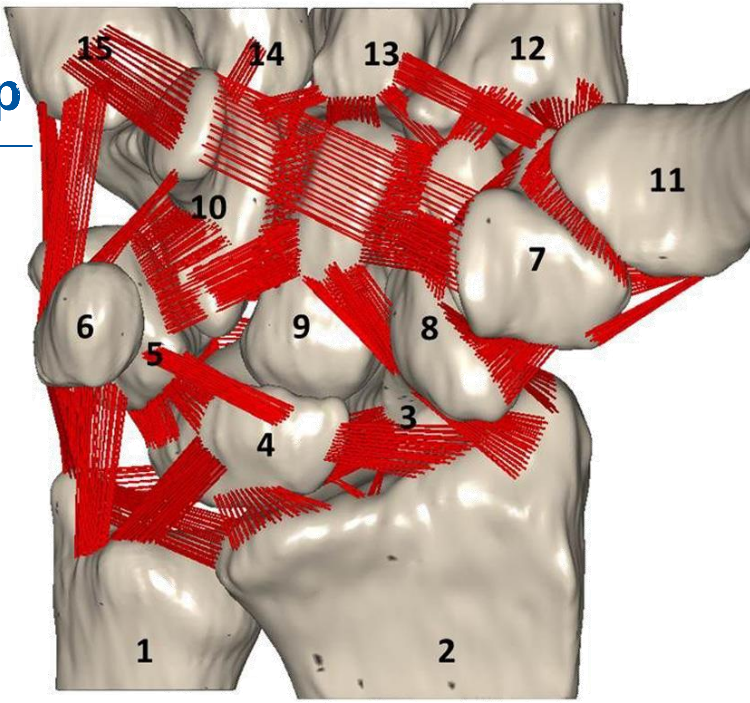


Material and Methods – General model setup

- A 3D model of the wrist joint was developed from scratch.
  - Bones:
    - 5 metacarpal bones
    - 8 carpal bones
    - 2 forearm bones
  - Ligaments:
    - 67 ligaments
    - each ligament has been approximated as a multi-string element
    - physiological wrapping of ligaments
    - ligament stiffness



[Eschweiler 2016b]

Palmar view on the carpus with ligaments
forearm: (1) ulna, (2) radius;

proximal row: (3) Scaphoid, (4) lunate, (5) triquetrum, (6) pisiform;

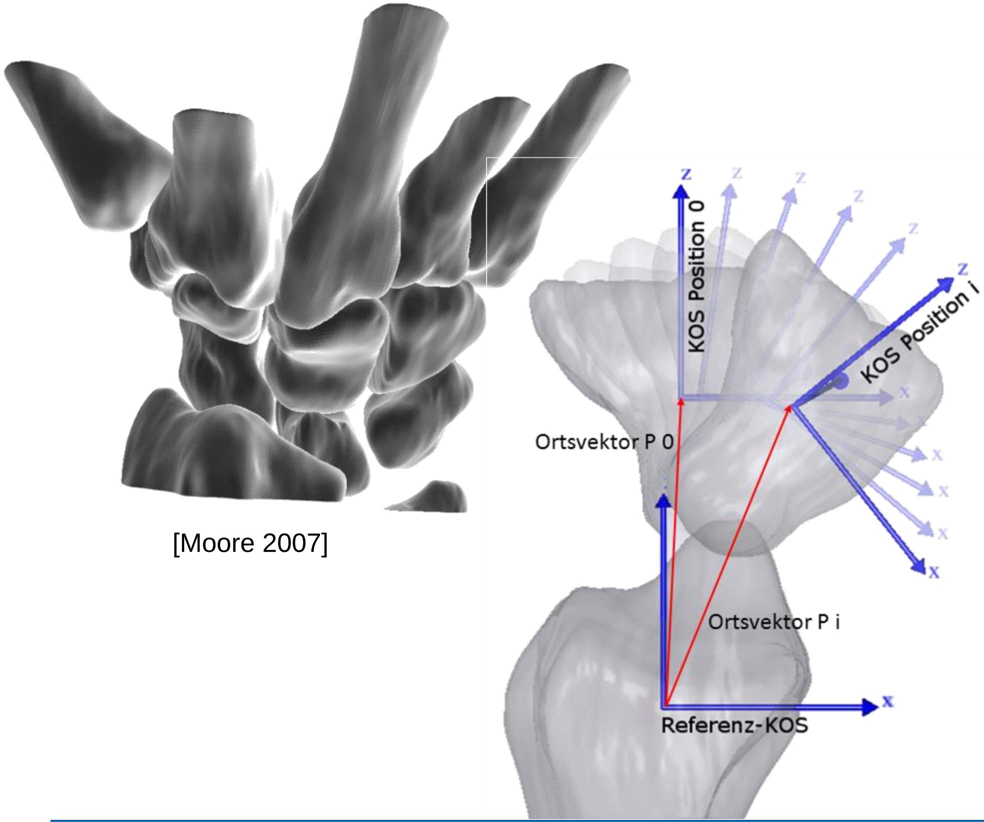
distal row: (7) trapezium, (8) trapezoid, (9) capitate, (10) hamate;

metacarpal bones: (11) metacarpal I, (12) metacarpal II, (13) metacarpal III, (14) metacarpal IV, (15) metacarpal V

Material and Methods – [Moore et al. 2007]

Database of Moore et al. [Moore 2007]**:**

- published a database of carpal bone anatomy (surface models) and kinematics from a large number of CT scans of healthy subjects (Table 1)
- provided the basis for a first step the generic morphologic and functional implementation as well as for an initial evaluation.



[Moore 2007]

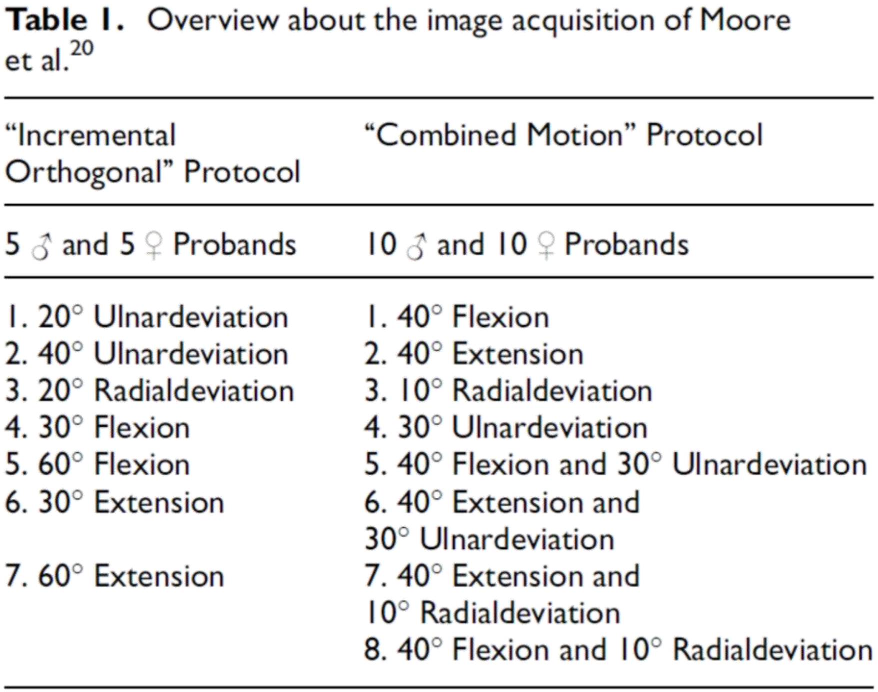


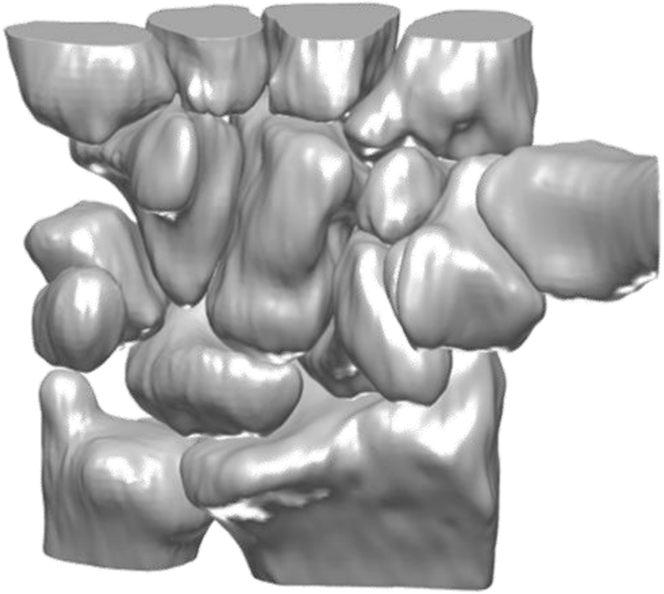
Table 1. Overview about the image acquisition of Moore et al.[20]

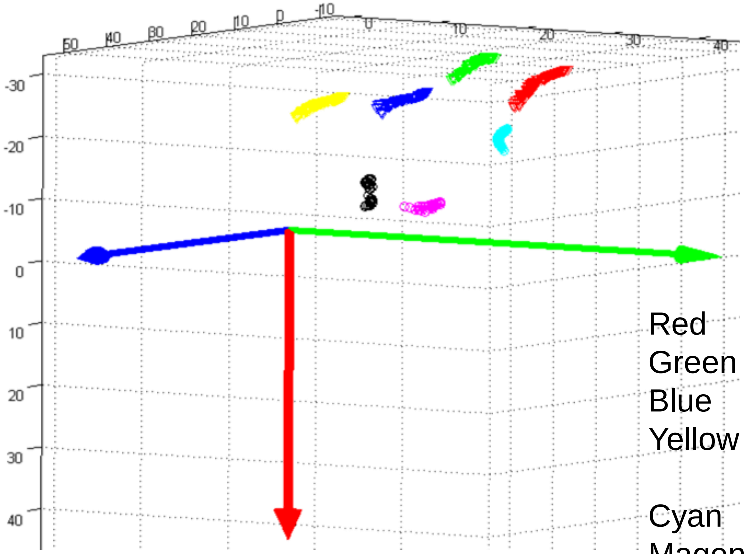
"Incremental Orthogonal" Protocol	"Combined Motion" Protocol
5 ♂ and 5 ♀ Probands	10 ♂ and 10 ♀ Probands
1. 20° Ulnardeviation	1. 40° Flexion
2. 40° Ulnardeviation	2. 40° Extension
3. 20° Radialdeviation	3. 10° Radialdeviation
4. 30° Flexion	4. 30° Ulnardeviation
5. 60° Flexion	5. 40° Flexion and 30° Ulnardeviation
6. 30° Extension	6. 40° Extension and 30° Ulnardeviation
7. 60° Extension	7. 40° Extension and 10° Radialdeviation
	8. 40° Flexion and 10° Radialdeviation

[Eschweiler 2016b]

Material and Methods – Own cadaver investigation

- Additional bone morphology data acquired from own CT scans (n=8) [Eschweiler 2016b]
- Own kinematic information were acquired (not only static position e.g. Moore et al., interpolation was necessary between the static position to get a motion trajectory)





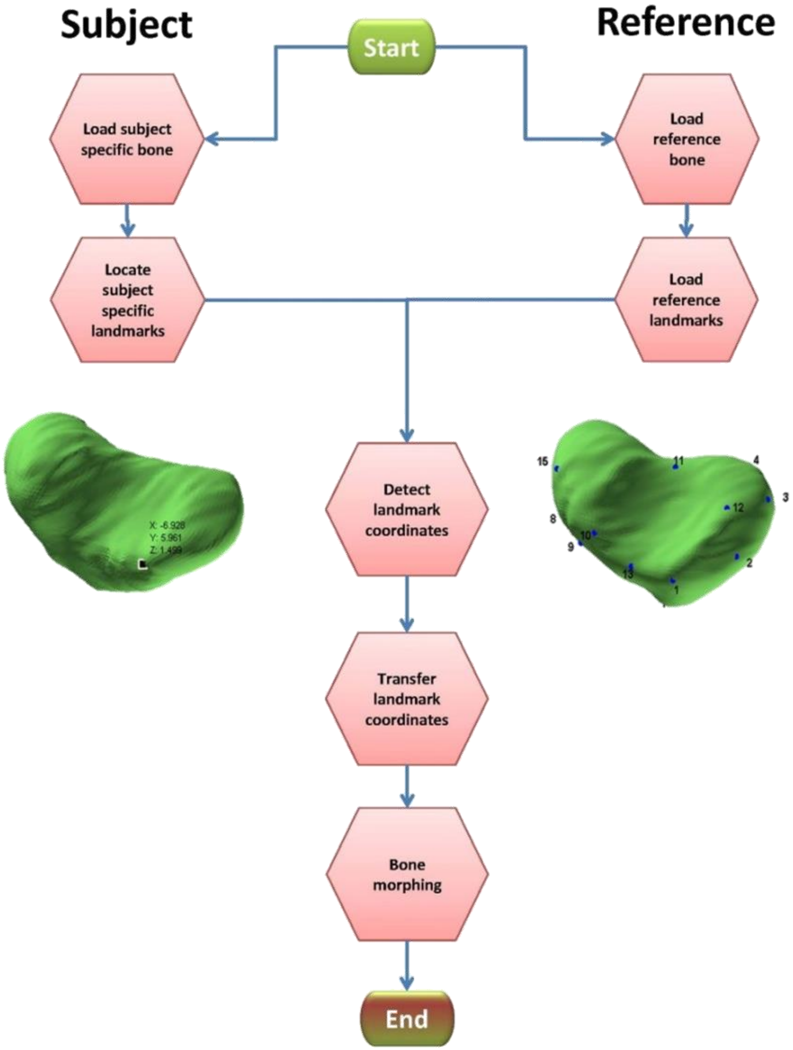
Red => Trapezium
Green => Trapezoid
Blue => Capitate
Yellow => Hamate

Cyan => Scaphoid
Magenta => Lunate
Black => Triquetrum

X-Axis => red
Y-Axis => blue
Z-Axis => green

Material and Methods – Bone morphing

- Individual adaption from other patient geometries
- Based on image information (MRI, CT)
- Future work => Ultrasound



Subject

Reference

Start

Load subject specific bone

Load reference bone

Locate subject specific landmarks

Load reference landmarks

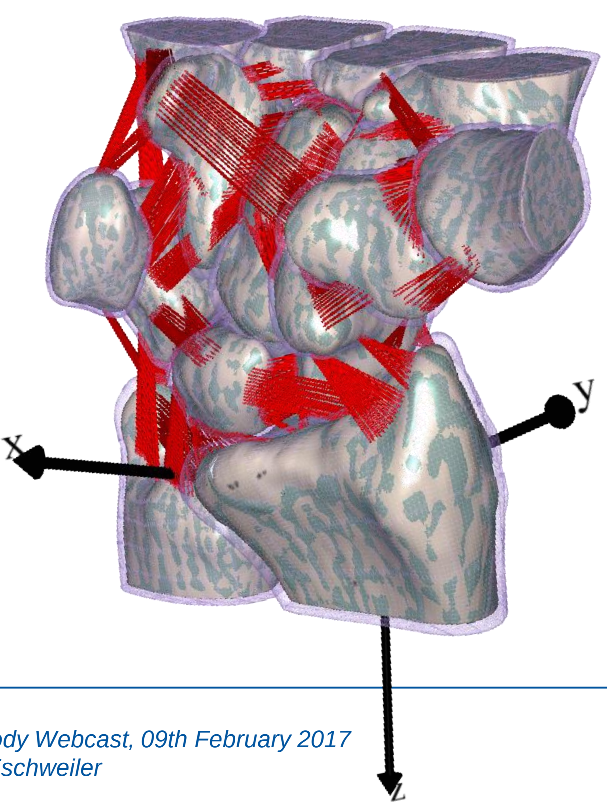
Detect landmark coordinates

Transfer landmark coordinates

Bone morphing

End

[Eschweiler 2016b]



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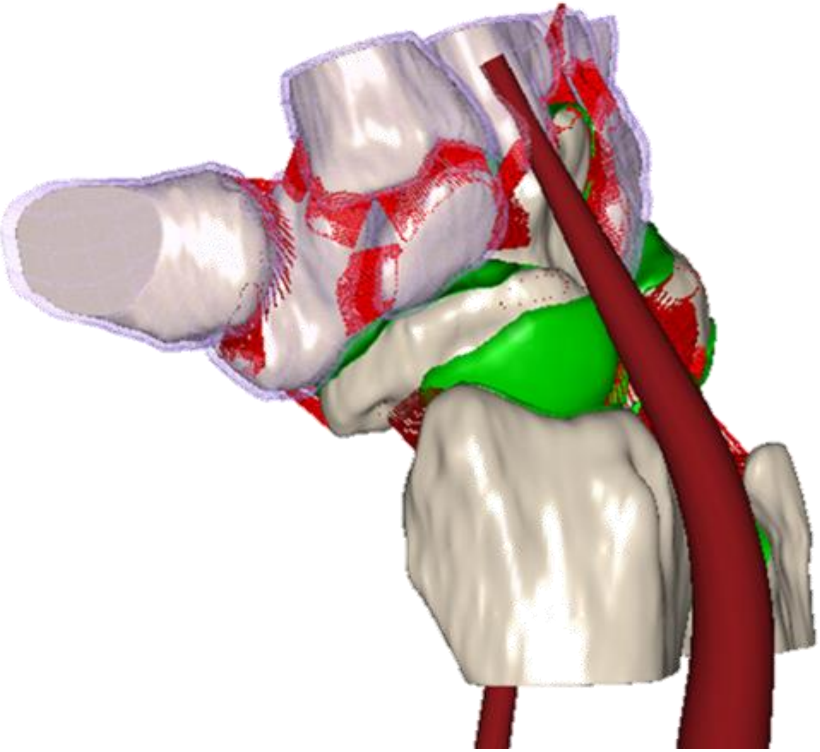
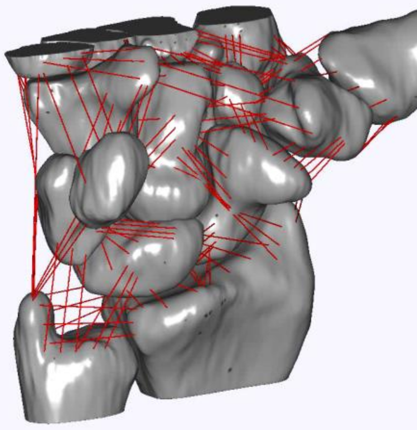
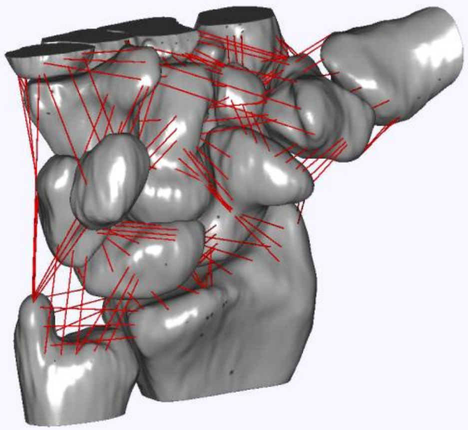


Material and Methods – Simulation setup

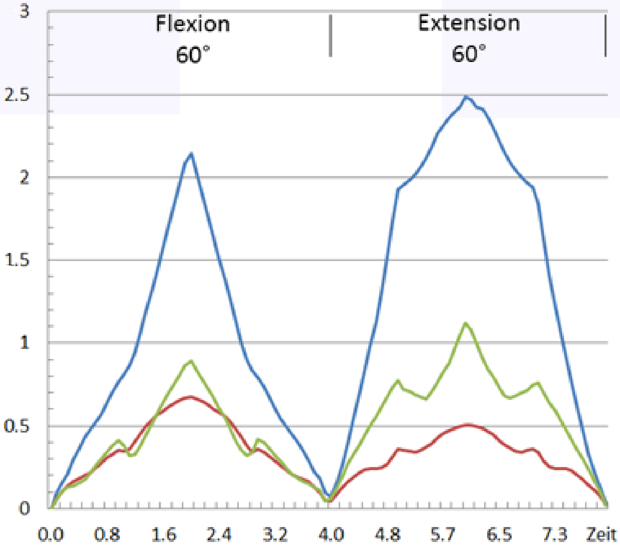
Physiological motion data (ID)



Force Dependent Kinematic (FDK)



Example:
Scaphoid

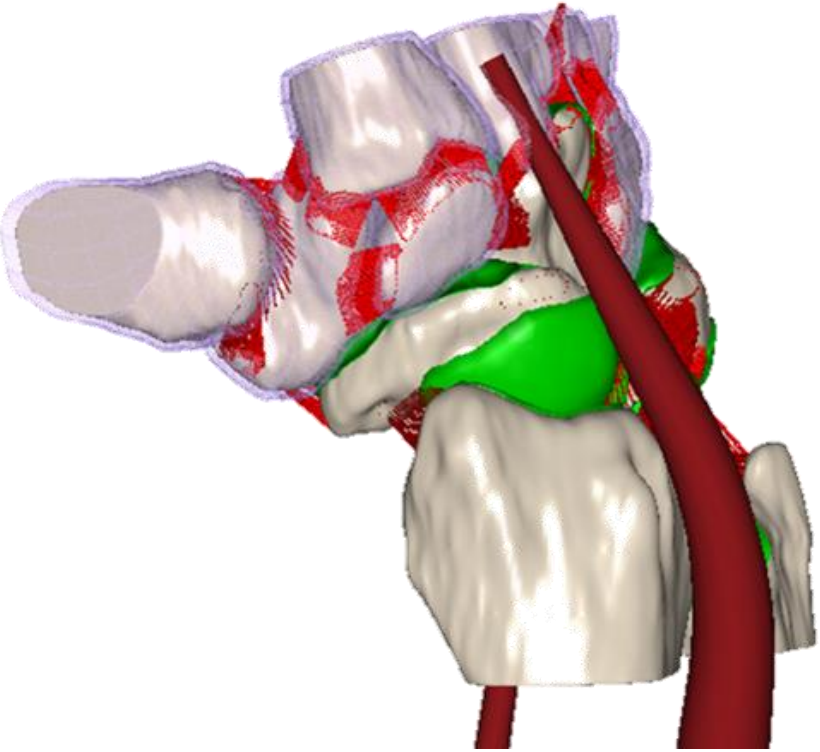


timesteps

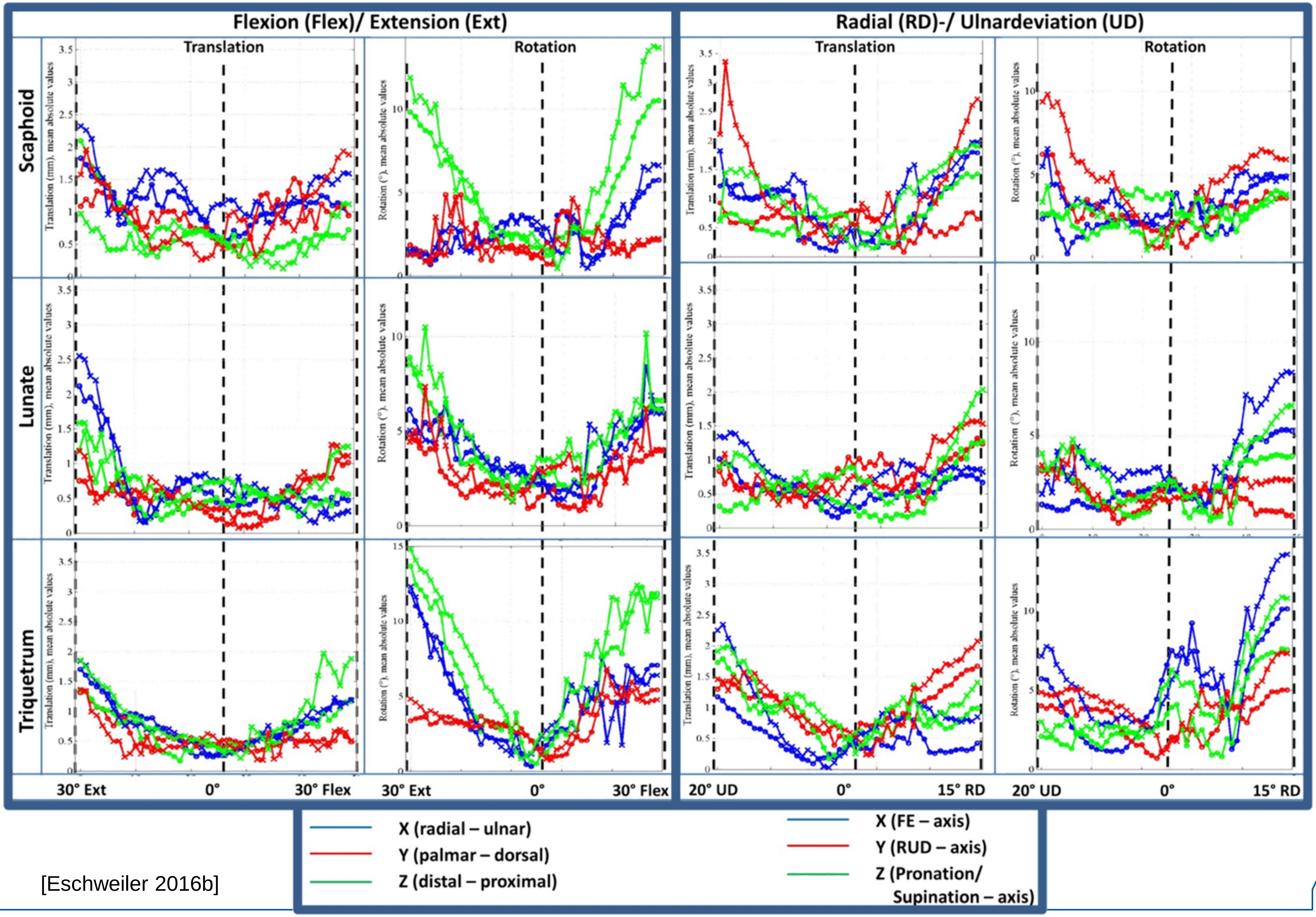
blue	x-axis - palmar/dorsal
red	y-axis - radial/ ulnar
green	z-axis - proximal/distal

Max. difference between real and simulated motion

Contents



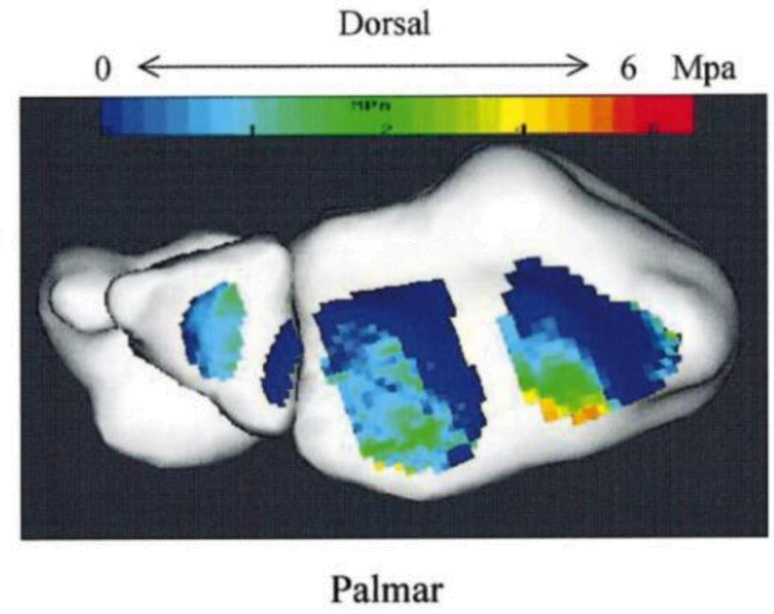
Results



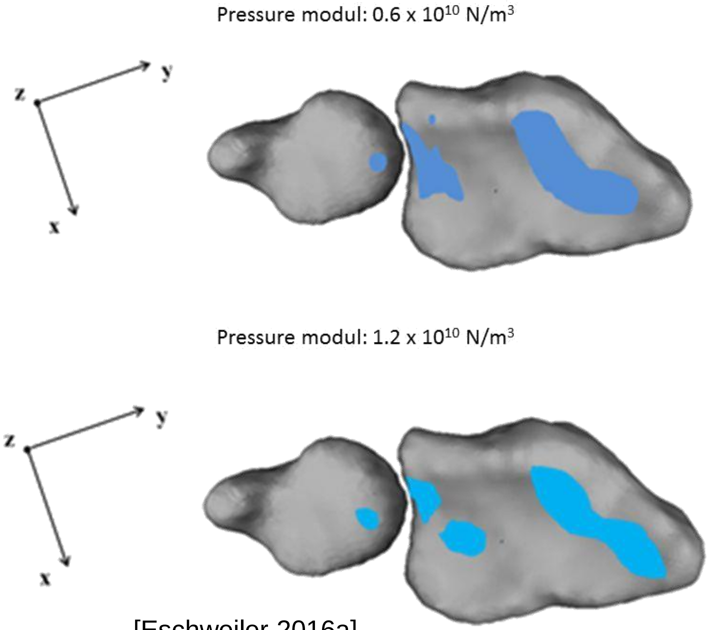
[Eschweiler 2016b]

Results

- Untreated, proximal row disruption leads to progressive and predictable scapholunate advanced collapse (SLAC) wrist arthritis, which is responsible for 55% of cases of degenerative wrist arthritis.
- SLAC wrist degenerative changes begin at the radiocarpal joint between the scaphoid and radius, and progress over time to the midcarpal joint.



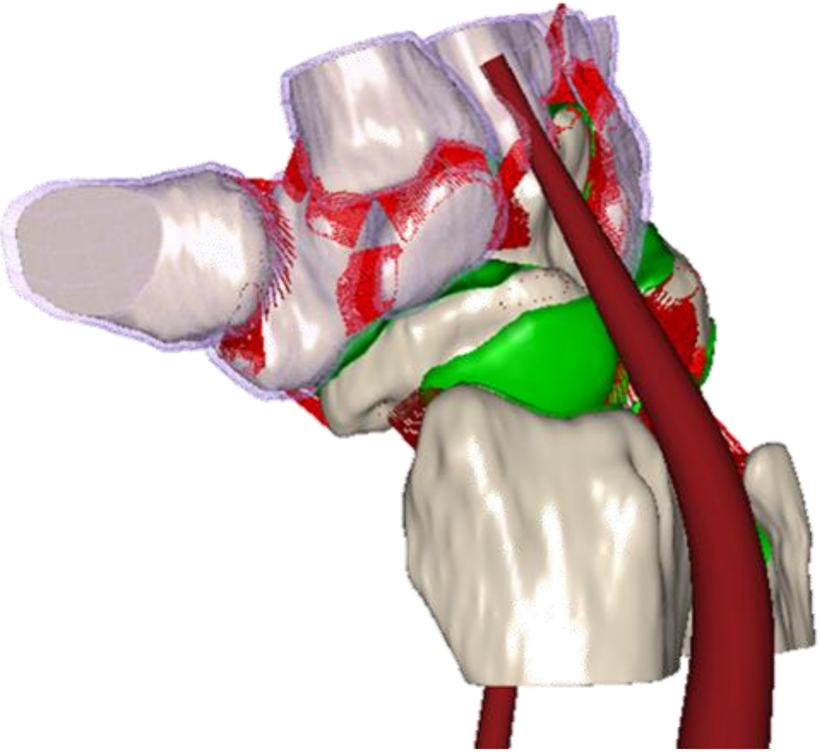
[Genda 2000]


Pressure modul: 0.6 x 10^{10} N/m^3

Pressure modul: 1.2 x 10^{10} N/m^3

[Eschweiler 2016a]

Contents

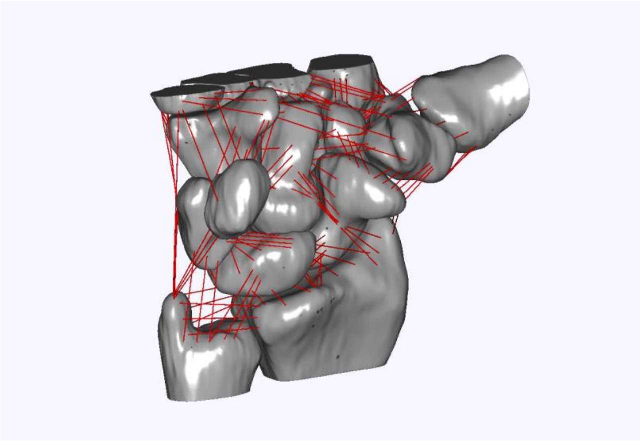


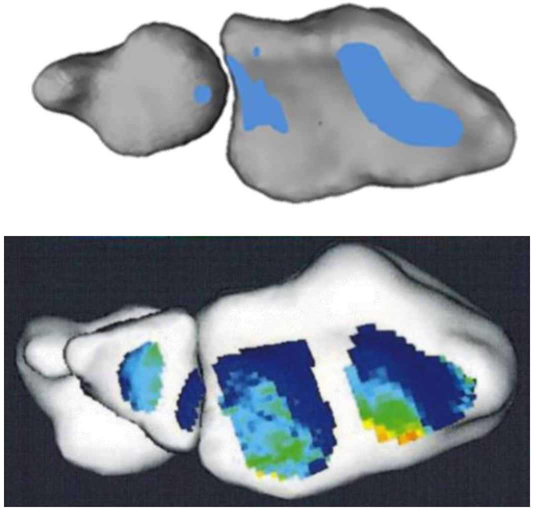
Discussion

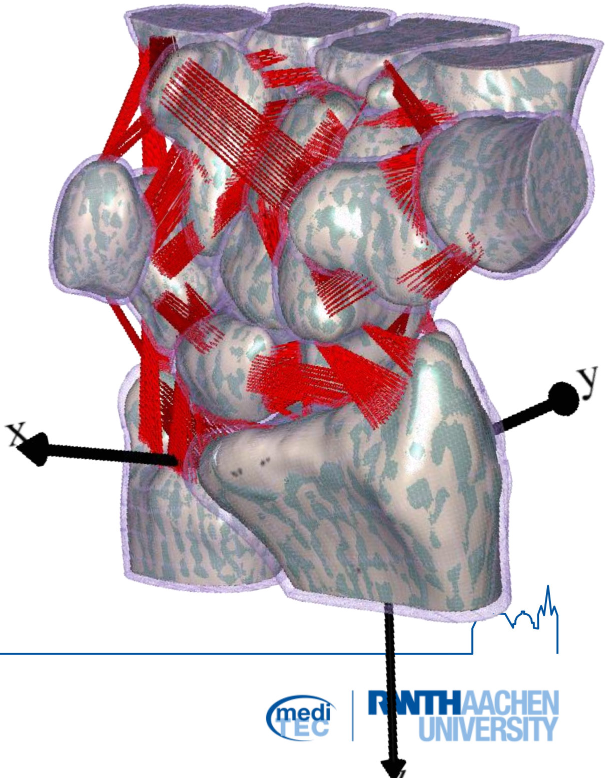
✓ Presently, good correlation between real kinematic behavior and simulated motion

✓ Presently, good correlation between measured applied stress on the forearm and simulated stress application

✓ Possibility of patient specific adaption of the model

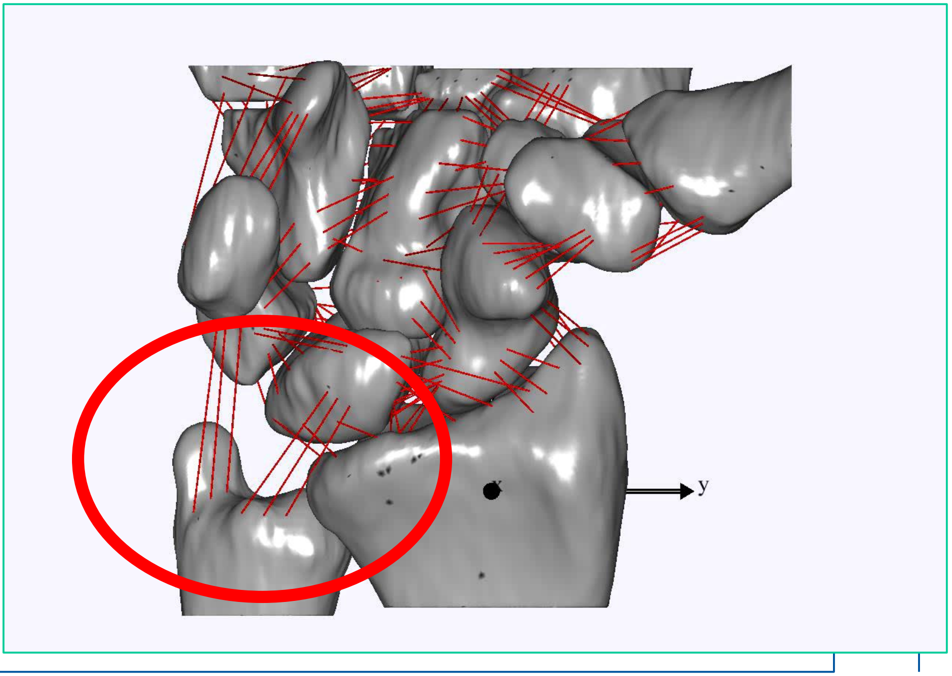






Discussion - Limitations

- ✗ Influence of missing soft tissue on motion behavior, e.g. including skin and full forearm muscle insertion tendons
- ✗ stiffness values for some specific ligaments are missing
- ✗ the articular cartilage was not captured by CT imaging



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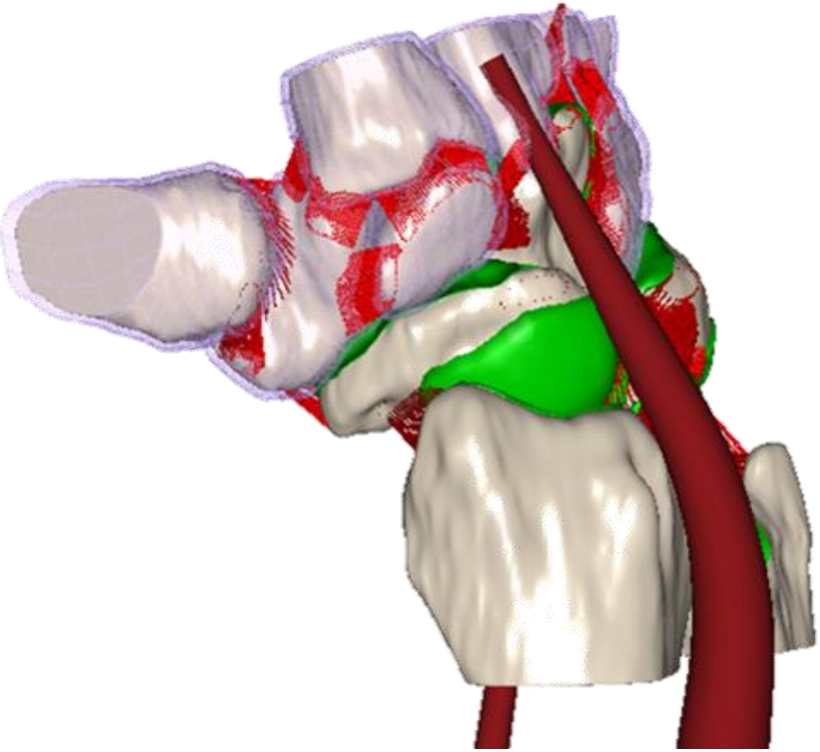
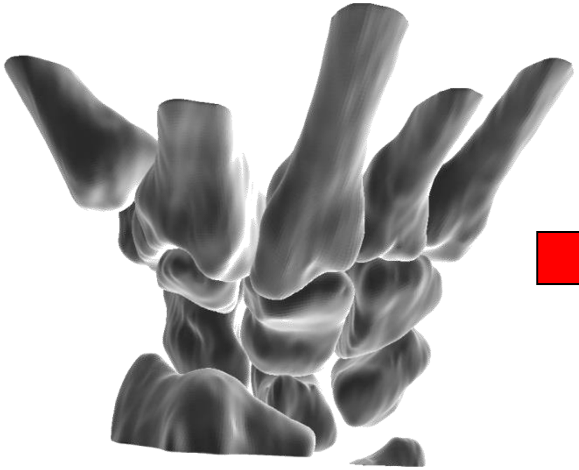


Conclusion

- In conclusion, obtained data from the presented wrist joint model indicate a good agreement with the available literature.
- Simulation model can be used to investigate:
    - pressure distributions and
    - range of motion of wrist joint pathologies and their treatment options.
- Moreover, the biomechanical computational model could be used to help surgeons to get an impression of the outcome of complex operations.

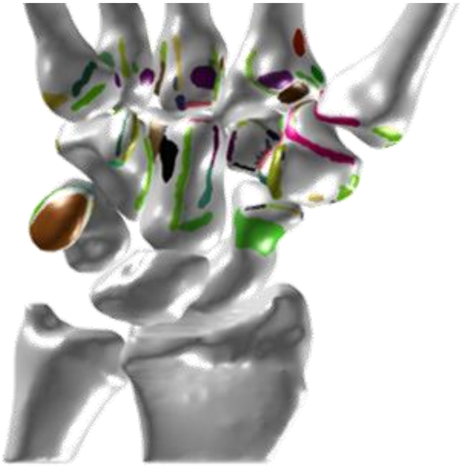
Future Work

Moore Database

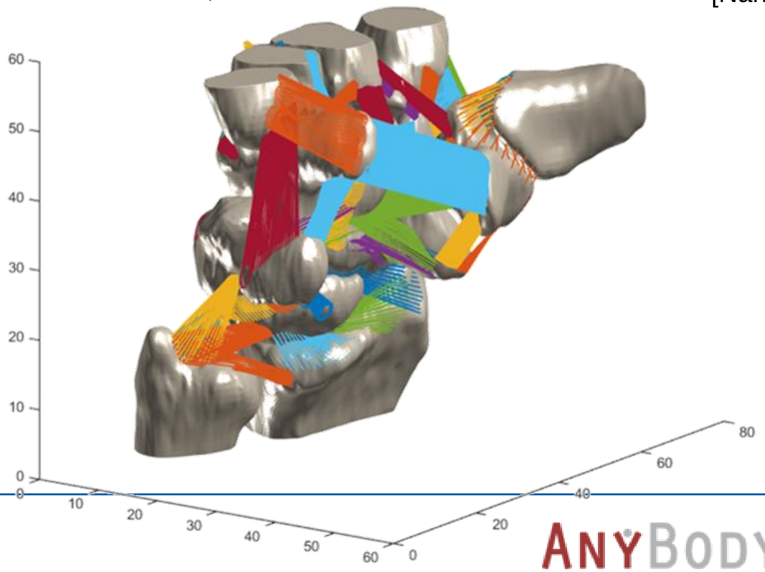


[Moore 2007]

Nanno Database



[Nanno 2007]



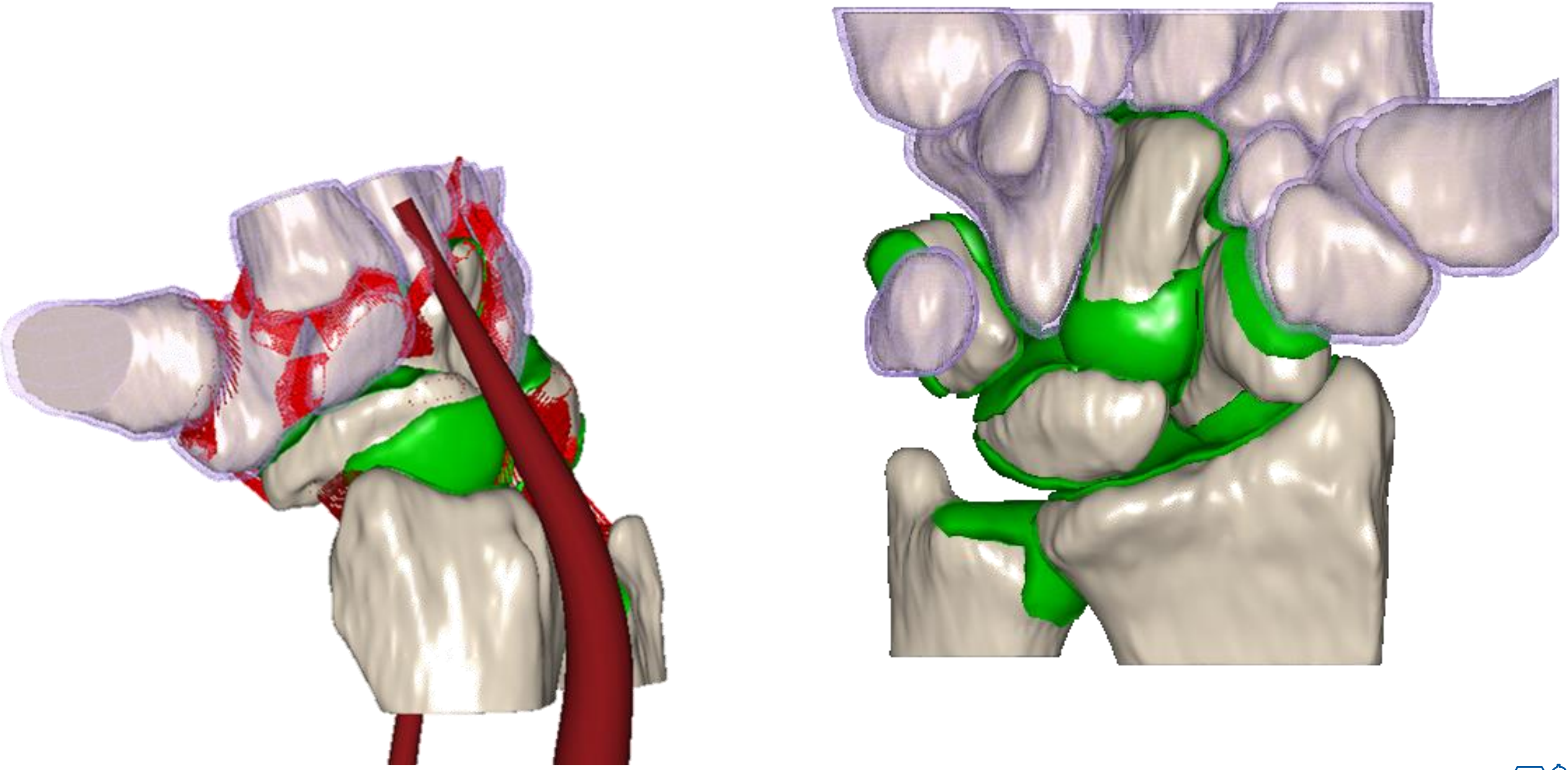
Cadaver study:

- Soft tissue,
- Bony information and
- Kinematics

of one cadaver

Future Work

- Implementation of cartilage
- Implementation of soft tissue structures (e.g. TFCC)
- Physiological „wrapping“ of muscles



- The abstract submission deadline has been extended to February 12, 2017. **Do not miss this opportunity and send your paper.**

- **Short facts at a glance**
  Conference: 17th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery
  Date: June 14–17, 2017
  Venue: Eurogress Aachen (Germany)

- **Early bird deadline:** March 31, 2017

- **Pre-conference educational workshops:** June 14, 2017

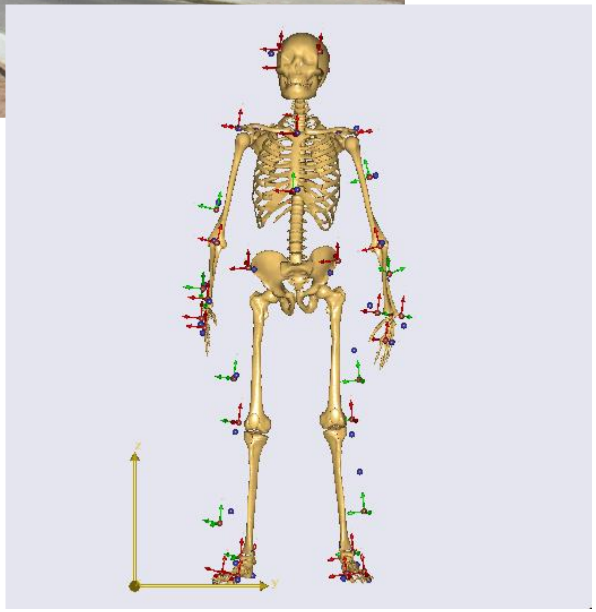
Development of a biomechanical model of the wrist joint for patient-specific model guided surgical therapy planning

Jörg Eschweiler, PhD

Maximilian M. C. Fischer, Dipl.-Ing.

Klaus Radermacher, PhD

Thank you !



Chair of Medical Engineering

Helmholtz-Institute for Biomedical Engineering of the RWTH Aachen University, Germany

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Webcasts

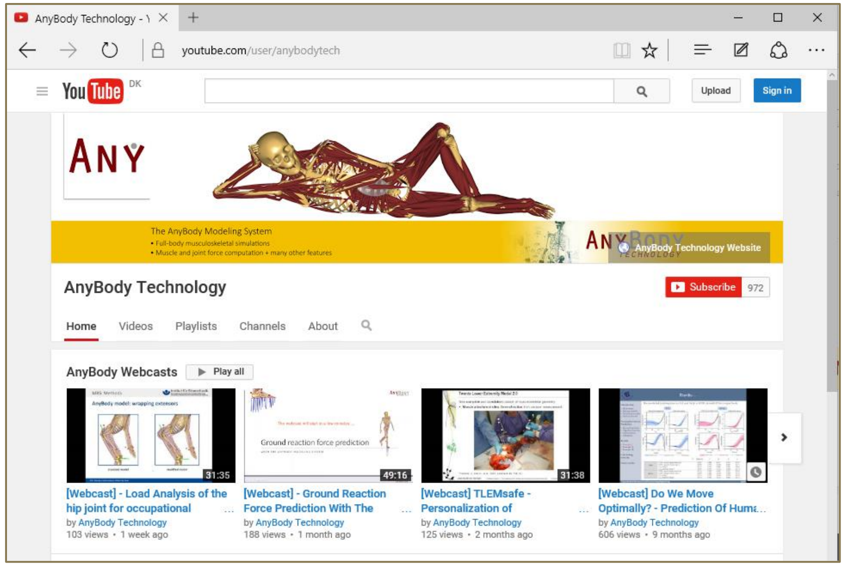
- Stay tuned for next webcast
  - More information will follow by mail.
- Check our YouTube channel for previous webcast
  - Search channels for ‘AnyBody Technology’

www.anybodytech.com

- Events, dates, publication list, ...

www.anyscript.org

- Wiki, Forum



The AnyBody Modeling System
• Full-body musculoskeletal simulations
• Muscle and joint force computation + many other features

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Events

- **14-18 Mar:** Let’s meet at AAOS 2017 – The Annual Meeting in San Diego, CA
- **19-22 Mar:** Let’s meet at ORS 2017 – The Annual Meeting in San Diego, CA
- **27-31 Mar:** Register for Aalborg Uni’s next AnyBody course in Denmark
- 

  17th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery
  14–17 JUNE 2017 I AACHEN (GERMANY)

  http://www.caos2017.de

Time for questions: