Biomechanical outcome after computer-assisted Femur First vs. conventional THR

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Musculoskeletal computations

Medical image processing

Implant system

Finite Elemente Analysis

Outline

1. Introduction
2. V&V – Verification and Validation
3. Study Results and Discussion
4. Outlook

Introduction

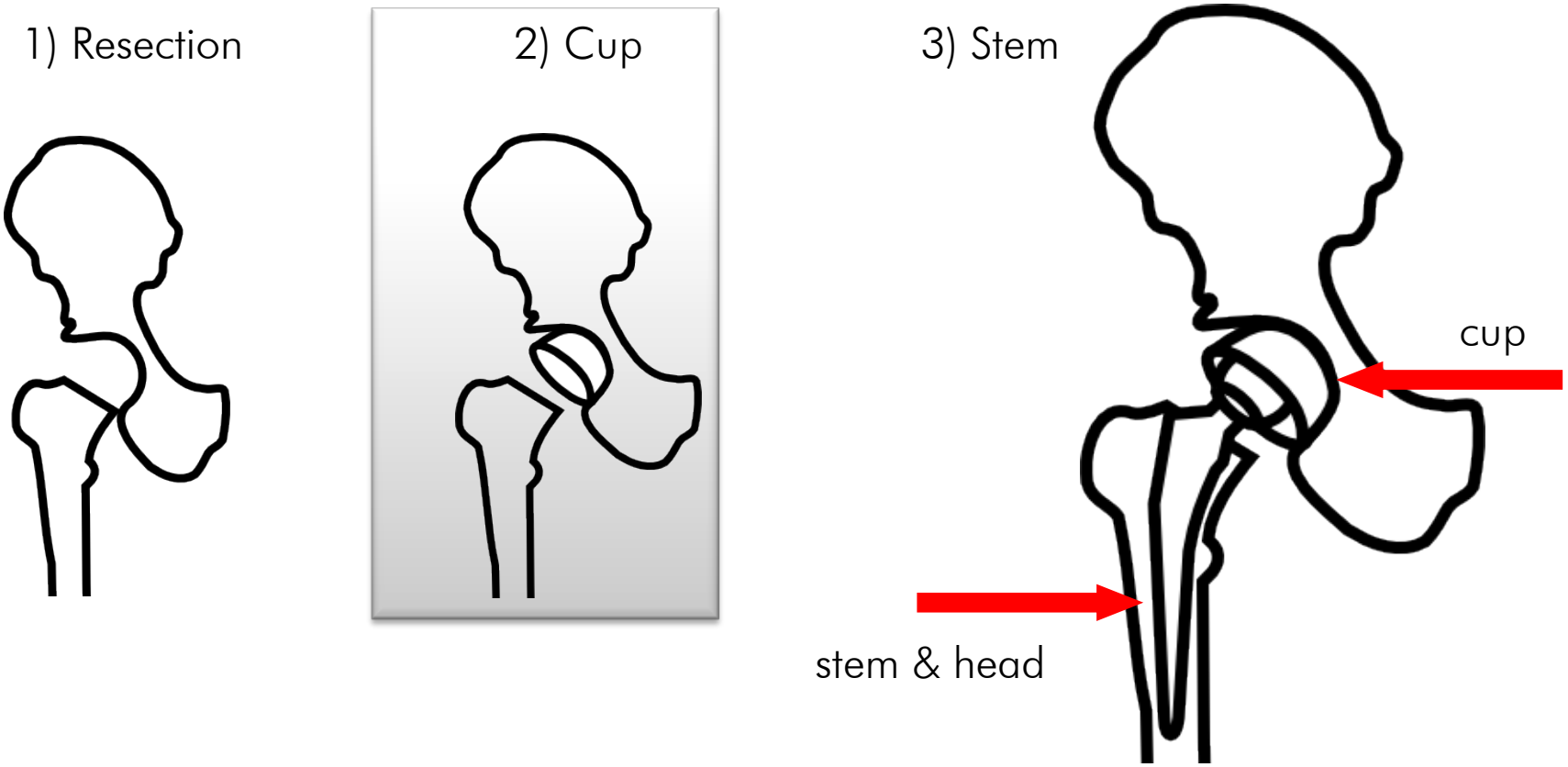
- Increasing numbers of patients that are subject to Osteoarthritis (OA)

- OA in the hip is the leading cause for
  - Pain
  - Stiffness
  - Difficulty in moving (limited range of motion)

- 300,000 Total Hip Replacements (THR) in Germany[1]

[1)] OECD: Health at a Glance 2013: OECD Indicators.

Total hip replacement (THR)

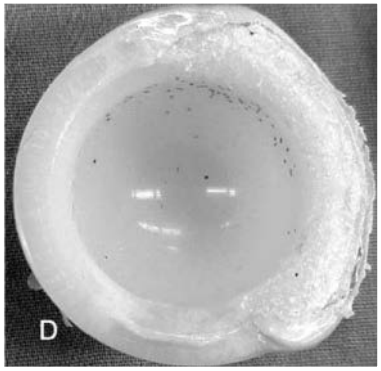


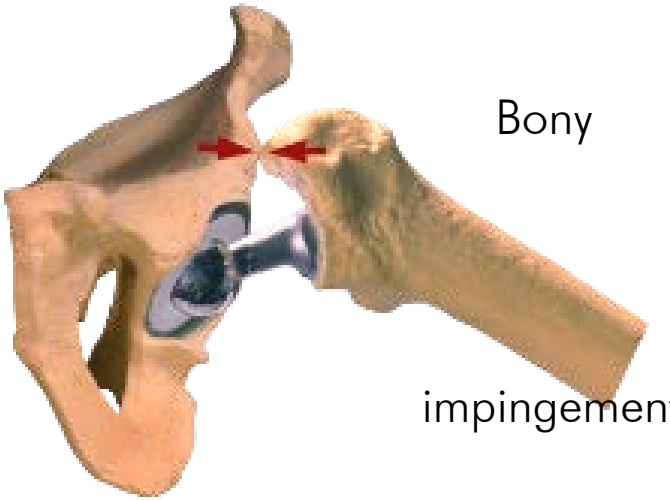
- Up to 25% are still failing[1] --- but why?

1) Melvin et al.: Early Failures in Total Hip Arthroplasty – A Changing Paradigm. 2013

Clinical challenges

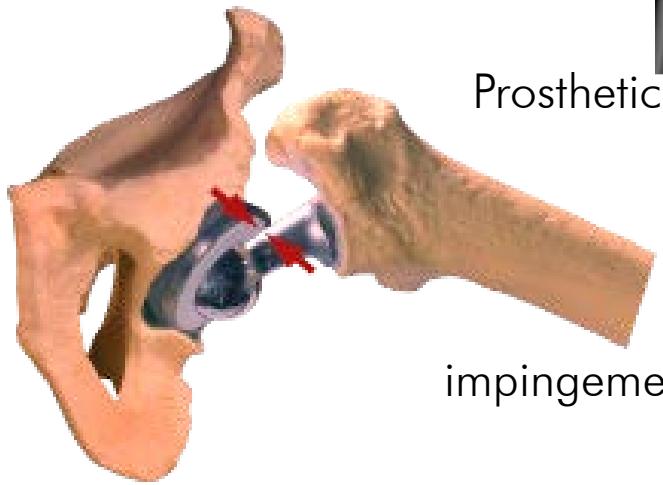
- Malpositioning leads to
  - Impingement
  - Increased wear rates and
  - Increased risk for dislocation





Bony

impingement



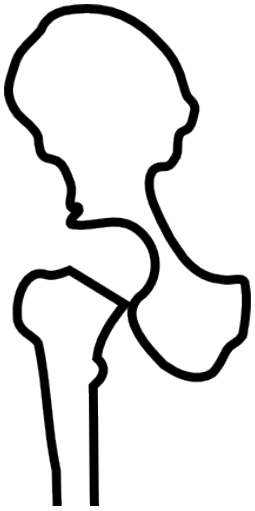
Prosthetic

impingement

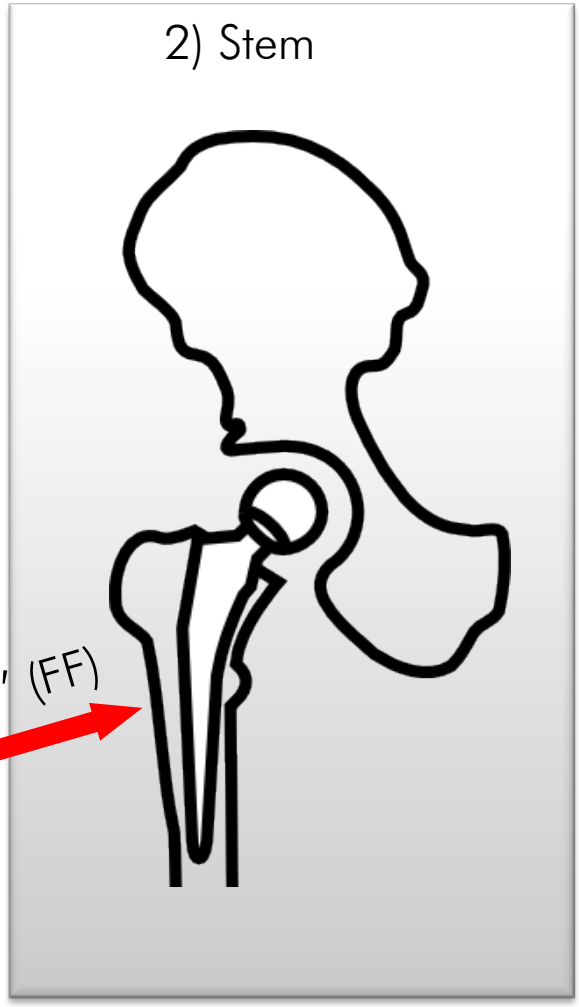
1) Shon et al.: Impingement in total hip arthroplasty a study of retrieved acetabular components. 2005
2) Patel et al.: The dislocating hip arthroplasty: prevention and treatment. 2007

Femur First

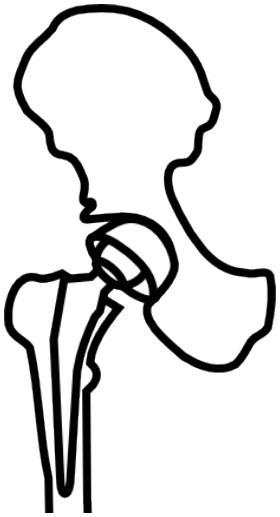
1) Resection



2) Stem



3) Cup

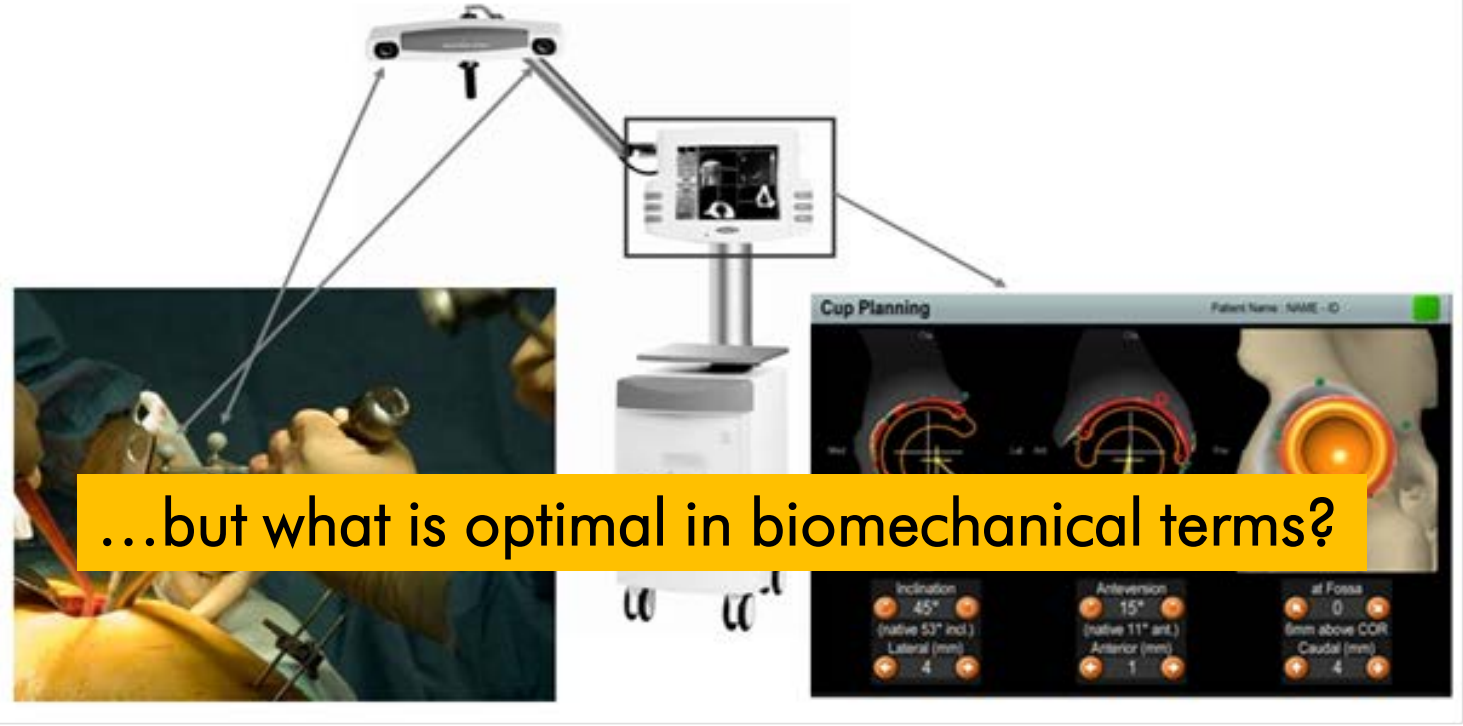


1) Sendtner et al.: [Femur first in hip arthroplasty--the concept of combined anteversion]. 2010.

CAS - Computer assisted surgery

- Guided surgery to position implant system with respect to patient anatomy
- Imageless, motion-capture (MoCap)

Optimal implant positioning may lead to decreased wear and impingement rates



…but what is optimal in biomechanical terms?

1) Renkawitz et al.: Development and evaluation of an image-free computer-assisted impingement detection technique for total hip arthroplasty. 2012.

Study protocol – patients

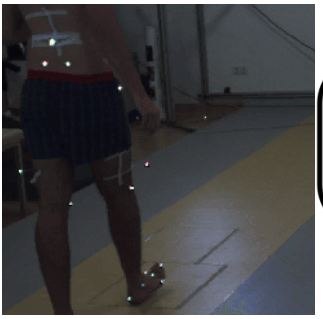
- 60 Patients (28 CAS FF/32 CON)
  - Subgroup of the FemurFirst[1] study
- Pre-op, 6 months post-op, 12 months post-op gait analysis
- Post-op CT-Scan of all patients
- Randomized
- Double – blinded
- Ethics approval

[1)] Renkawitz et al. Minimally invasive computer-navigated total hip arthroplasty, following the concept of femur first and combined anteversion: design of a blinded randomized controlled trial. 2011

Study hypothesis

Outcome variable	Hypothesis
Hip reaction force - Magnitude - Symmetry	- Magnitude closer to healthy in CAS group - Symmetry increased in CAS group
Hip reaction force orientation - Distance to rim - At peak loads	- Distance to rim increased in CAS group - Distance to rim at peak loads increased in CAS group

Workflow



acquisistion of volunteer patients/subjects
- anthropometrics
- anatomy

gait analysis
- motion capture (marker trajectories)
- ground reaction force

input for...

input for...

ANYBODY TECHNOLOGY
musculoskeletal model

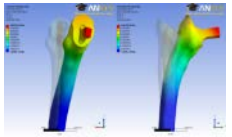
scaling
input:
anthropometrics, MoCapData
medical imaging
output:
segment lengths & massses
joint positions

kinematic analysis
input:
scaling, gait analysis
output:
- gait pattern (joint angles)

inverse dynamics analysis
input:
kinematic analysis
output:
joint forces, muscles forces

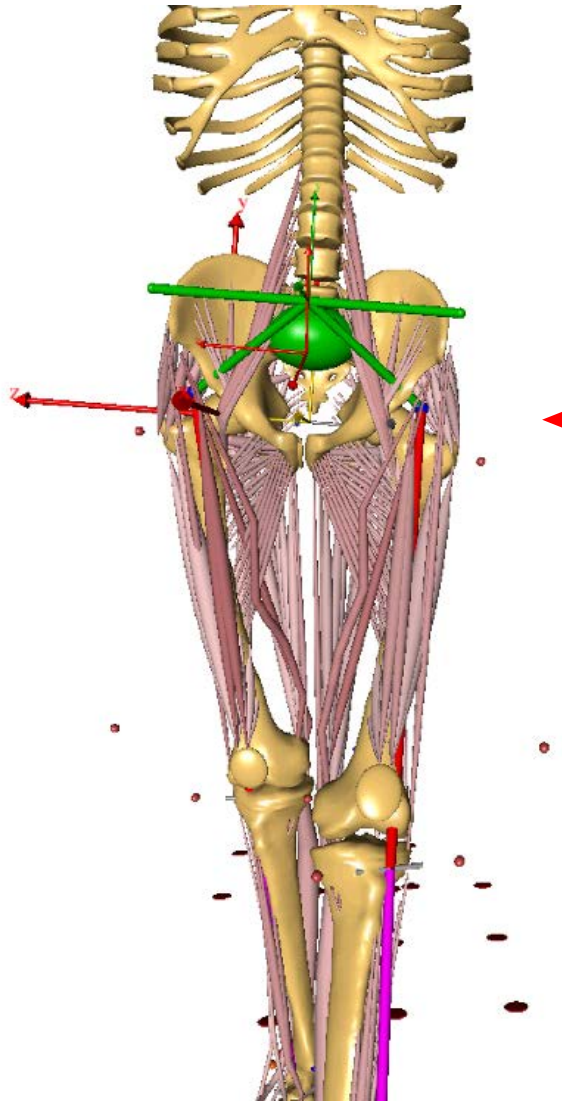
Evaluation
- Forces[1]
- Kinematics

Evaluation
- Stress/Strain



1) Weber et al.: Measuring functional outcome after total hip replacement with subject-specific hip joint loading. 2012
2) Dendorfer et al.: Musculoskeletal modeling for hip replacement outcome analyses and other applications. 2014

Model



- Over 150 individual activated muscles
- Highly accurate due to non-linear scaling[1]
- Cubic muscle activation scheme

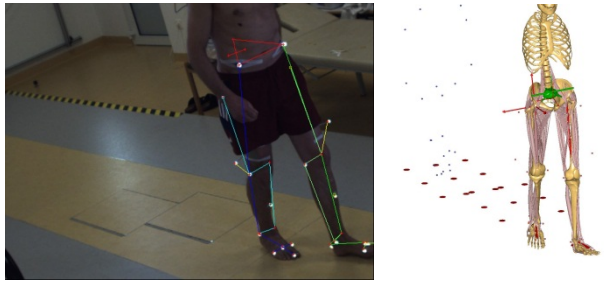
$$G = \sum_i \left(\frac{mf_i}{N_i} \right)^3$$

1) Andersen et al.: The effect of including accurate pelvis bony landmarks in a nonlinearly scaled musculoskeletal lower extremity model. 2012

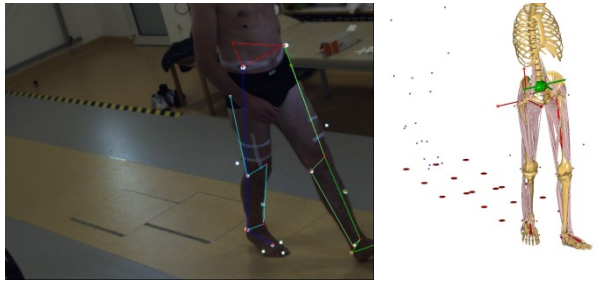
MoCap to Model

P24, CAS FF, operated: left

t0 – pre operativ

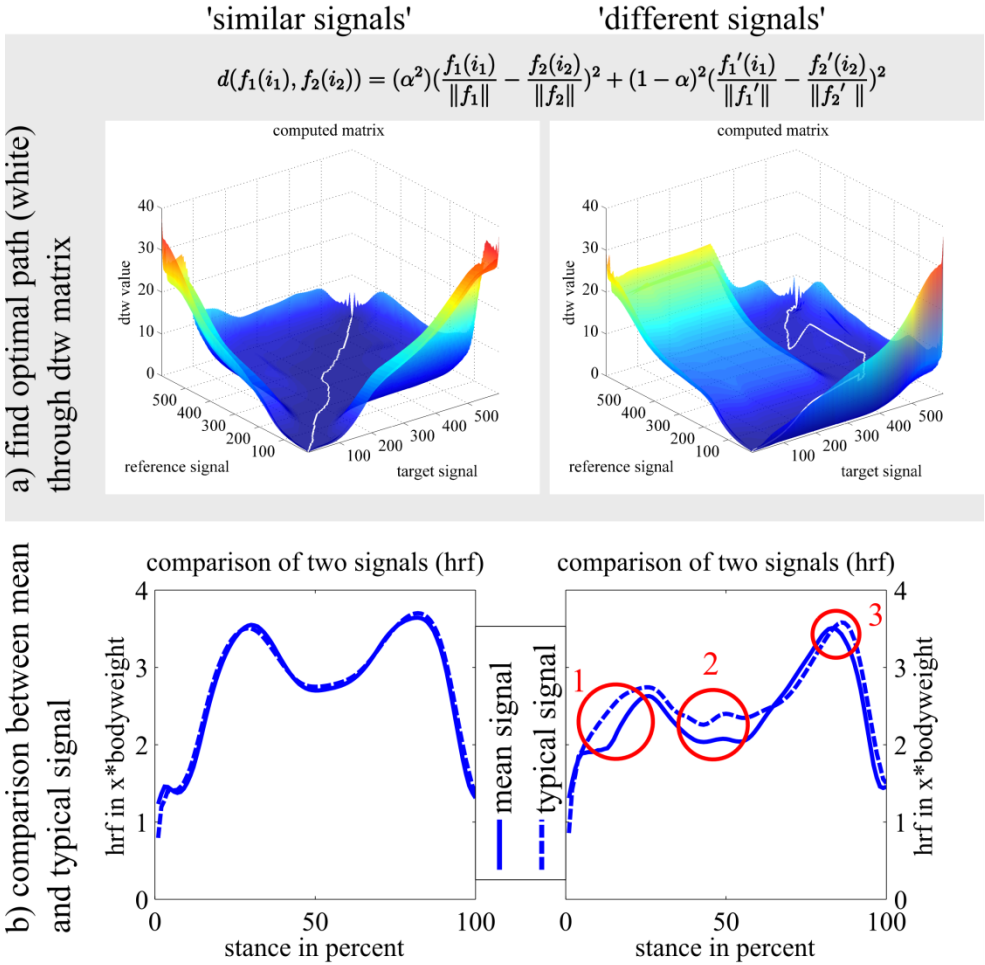


t1 – 6 month post operativ



Dynamic time warping

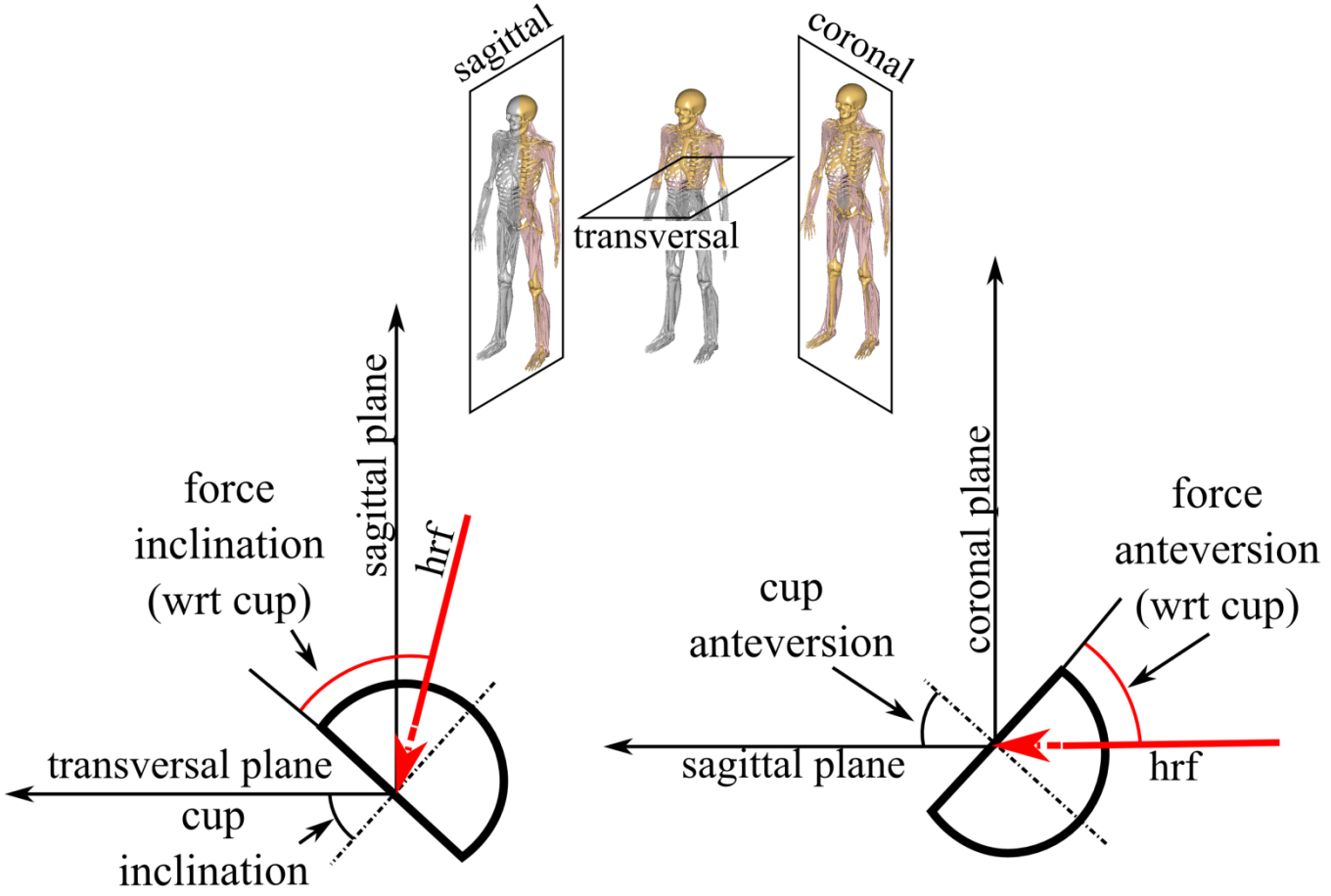
- "typical signals"[1]
- measure of shape similarity



1) Bender and Bergmann: Determination of typical patterns from strongly varying signals. 2012

Force orientation

- Radiographic coordinate system[1]



1) Murray: The definition and measurement of acetabular orientation. 1993.

Verification & Validation

Method verification

Research question	Source of variance	Study	Target parameter
Is the result obtained dependent on the MoCap Analyst?	MoCap Analyst	1 healthy subject (S1), 1 gait analysis, evaluated 10 times by 3 different examiners: A(experienced), B(experienced), C(not-experienced)	Standard error of mean (SEM) of hrf - HRF_{SEM}
How big is the influence of marker-placement on the results obtained	MoCap – marker placement	1 healthy subject (S1), 10 gait analysis, application of marker set in alternating manner by 2 analysts: A(experienced), B (experienced)	HRF_{SEM}
Is the method robust enough to produce repeatable results?	Measurement chain	3 healthy subjects (S1,S2,S3), 10 gait analysis, evaluation by 1 experienced analyst (A)	HRF_{SEM}

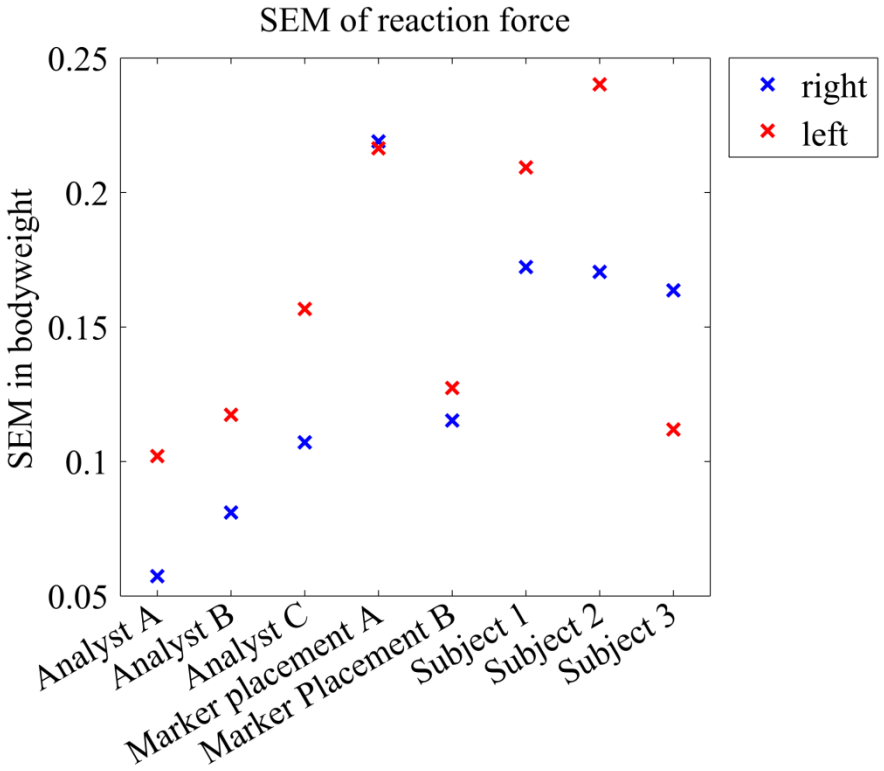
$SEM : standard\ error\ of\ the\ mean$

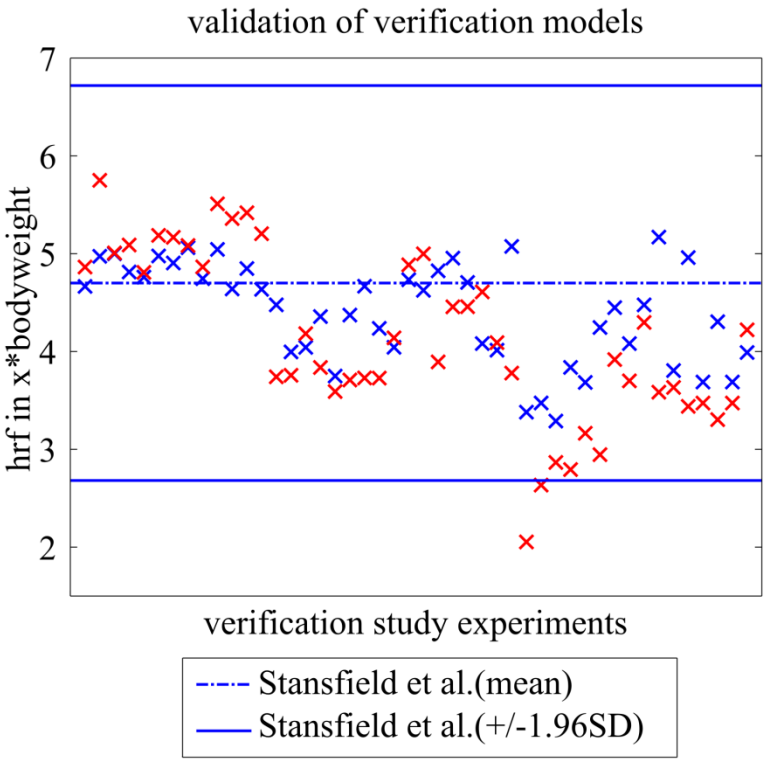
$$SEM(\bar{X}) = \frac{\sigma}{\sqrt{n}}$$

$\sigma : standarddeviation$

$n : samplesize$

Verification results

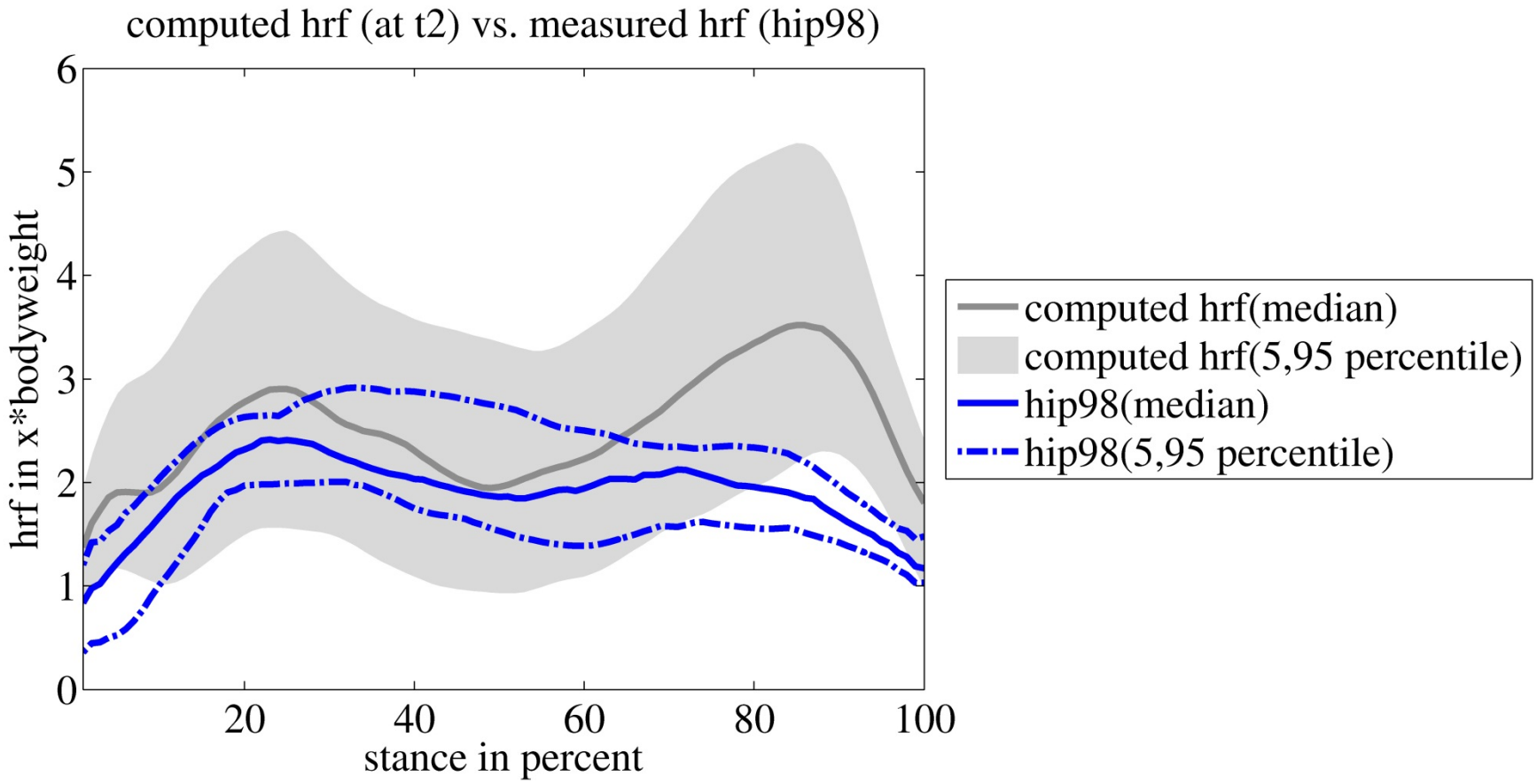




- Hrf accuracy: $2 \cdot max_{SEM} \sim 0.5BW$

1) Stansfield and Nicol: Hip joint contact forces in normal subjects and subjects with total hip prostheses: walking and stair and ramp negotiation. 2002.

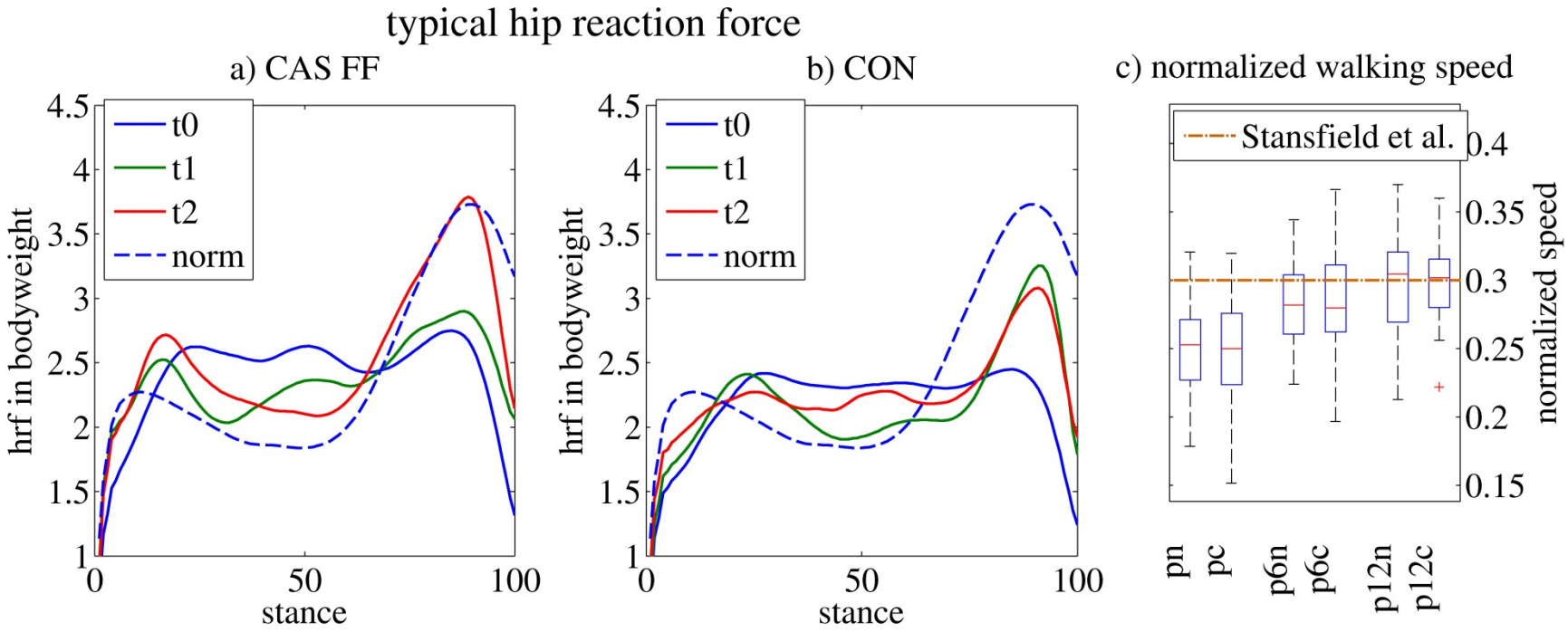
Model validation



1) Bergmann et al.: Hip contact forces and gait patterns from routine activities. 2001 - http://orthoload.com/

- STUDY RESULTS -

Hip reaction forces (hrf)

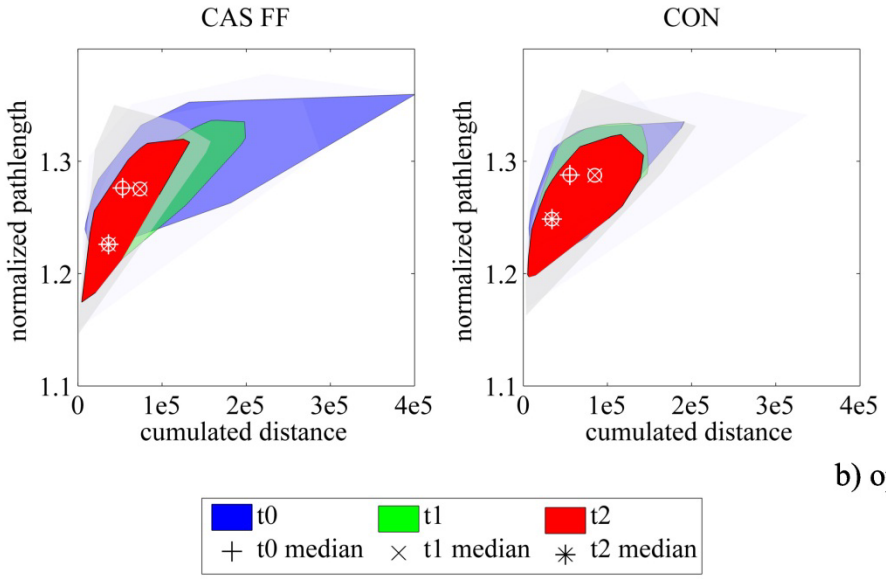


- Computed by means of dynamic time warping[1]
- Walking speed normalized to body height[2]

1) Bender and Bergmann: Determination of typical patterns from strongly varying signals. 2012.
2) Hof: Scaling gait data to body size. 1996.

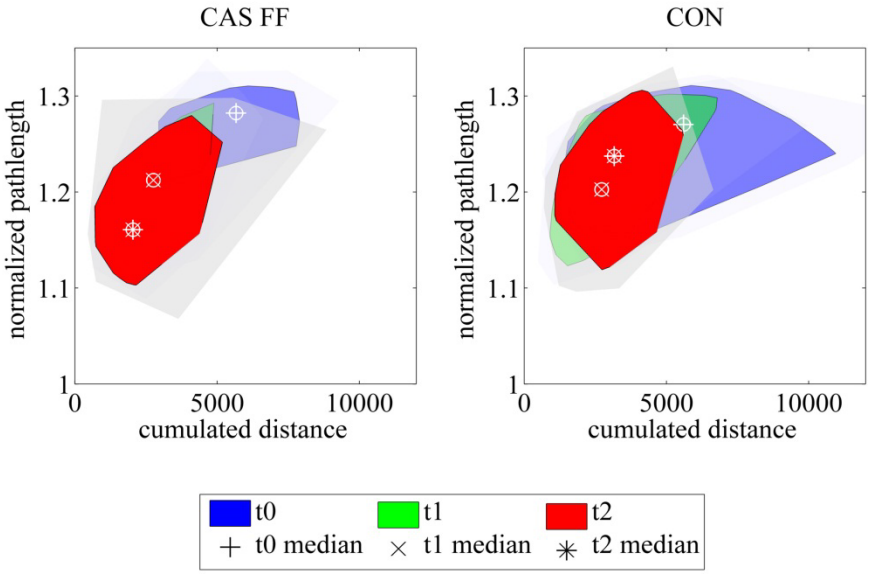
Asymmetry of hrf

a) operated vs. not-operated side



Pathlength: phase shift symmetry
Cumulated distance: magnitude symmetry

b) operated side vs. normative data



- Computed by means of dynamic time warping[1]

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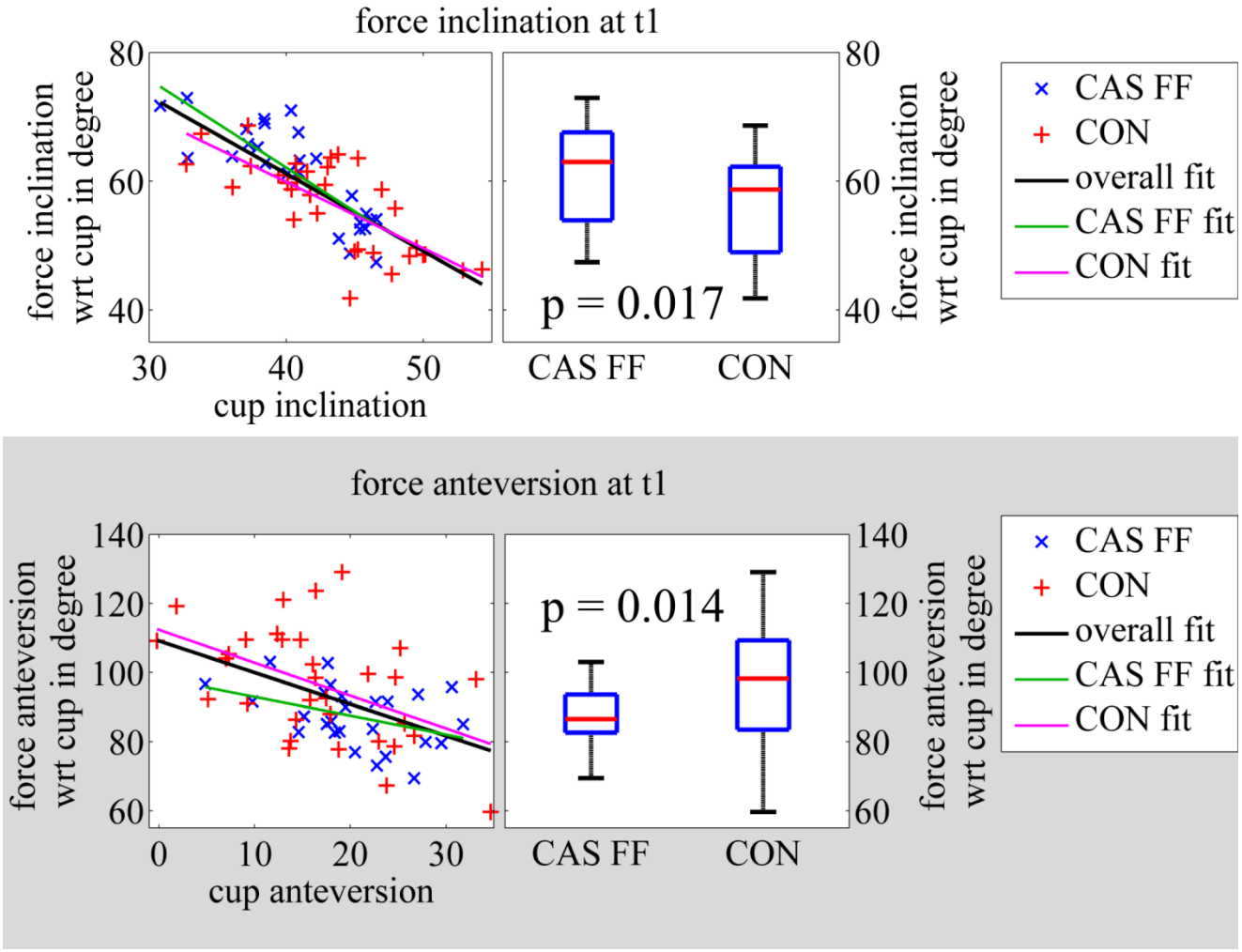
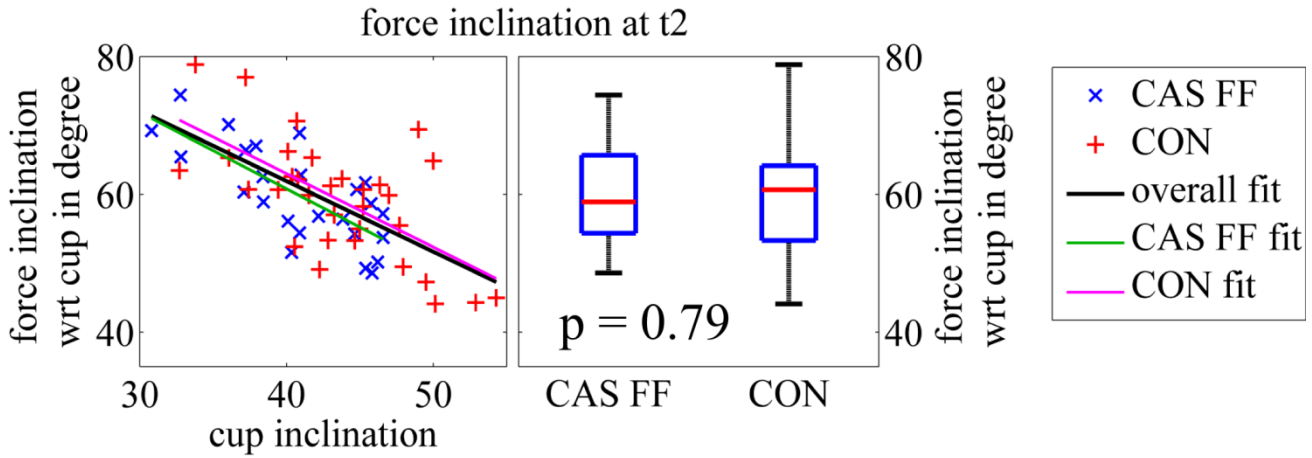
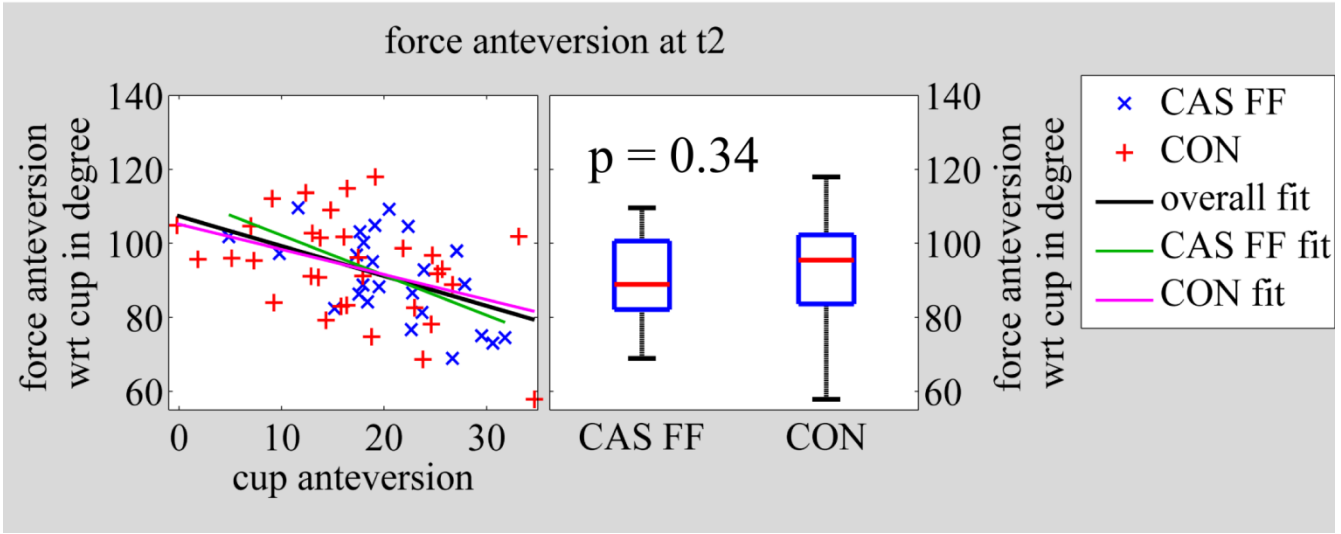
Hrf orientation (wrt cup)



Weber et al.: Measuring functional outcome after total hip replacement with subject-specific hip joint loading. 2012.

Hrf orientation (wrt cup)





Weber et al.: Measuring functional outcome after total hip replacement with subject-specific hip joint loading. 2012.

Discussion I

- Hip reaction forces:
  - CON hrf are closer to a healthy normal at 6 month postop
  - CAS FF hrf are closer to a healthy normal at 12 month postop
- Asymmetries:
  - decrease more in the CAS FF group, but insignificantly
  - CAS FF group closer to healthy normal in terms of phase-shift
- Orientation:
  - At t1 hrf Orientation of the CAS FF closer to optimal (90° - $p<0.05$)
  - At t2 no significant differences between the groups

Discussion II

- t1 (6 month):
  - CON hrf are closer to healthy normal
  - Hrf orientation is closer to optimum in the CAS FF group

Trend for lower propensity for impingement and dislocation early after surgery for CAS FF

- t2 (12 month) :
  - Increased phase-shift asymmetry
  - CAS FF are closer (practically the same) to healthy optimum

Possible long-term benefit due to restored walking ability for CAS FF patients

Strengths & limitations

- Comprehensive data set (32 vs. 28 patients)
  - Double blinded, randomized, prospective
- Validated and detailed model (AnyBody – AnyGait Model)
- Symmetry captures not only point of times, it is rather a measure of shape similarity

- Only post6, no earlier results
- Only walking as motion
  - More critically motions may be used for bigger effects (ethics)
- Greater sample size would increase statistic validity

Contact

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- Regensburg Center of Biomedical Engineering – rcbe.de

- Tim Weber (LBM,RCBE,UKR)
  - tim.weber (at) oth-regensburg.de
  - https://www.linkedin.com/pub/tim-weber/88/222/1a1

Thank you

Literature (in order of appearance):

- OECD: Health at a Glance 2013: OECD Indicators.
- Melvin et al.: Early Failures in Total Hip Arthroplasty – A Changing Paradigm. 2013
- Shon et al.: Impingement in total hip arthroplasty a study of retrieved acetabular components. 2005
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