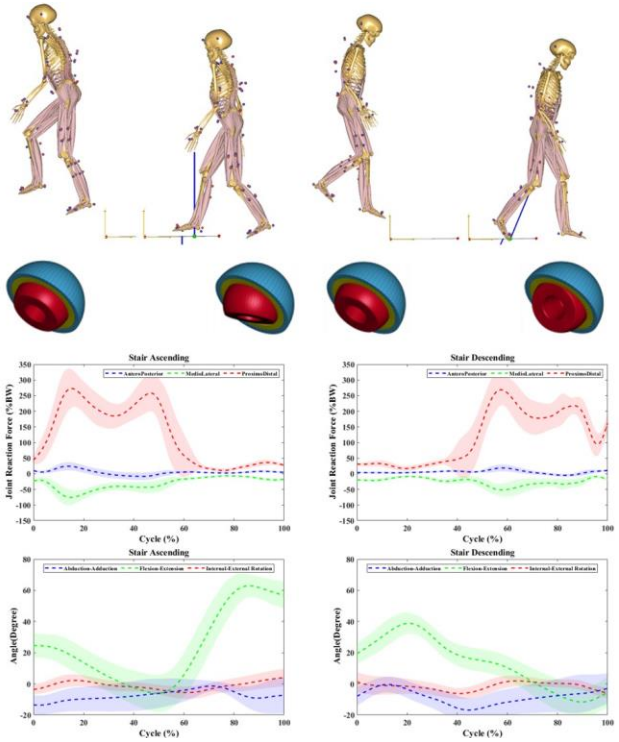
AnyBody Technology

May 13, 2024

Investigation of stair ascending and descending activities on the lifespan of hip implants



The webcast will begin shortly...

Outline

- Introduction to the AnyBody Modeling System
- Presentation
- Upcoming AnyBody events
- Question and answer session

Presenters

Associate Professor Dr Senay Mihcin

Alican Tuncay Alpkaya, PhD student

Mehmet Yilmaz, PhD student

Ahmet Mert Sahin, PhD student

Izmir Institute of Technology,

Izmir, Turkey

Host

Kristoffer Iversen

Technical Sales Executive

AnyBody Technology

Outline

- Introduction to the AnyBody Modeling System
- Presentation
- Upcoming AnyBody events
- Question and answer session

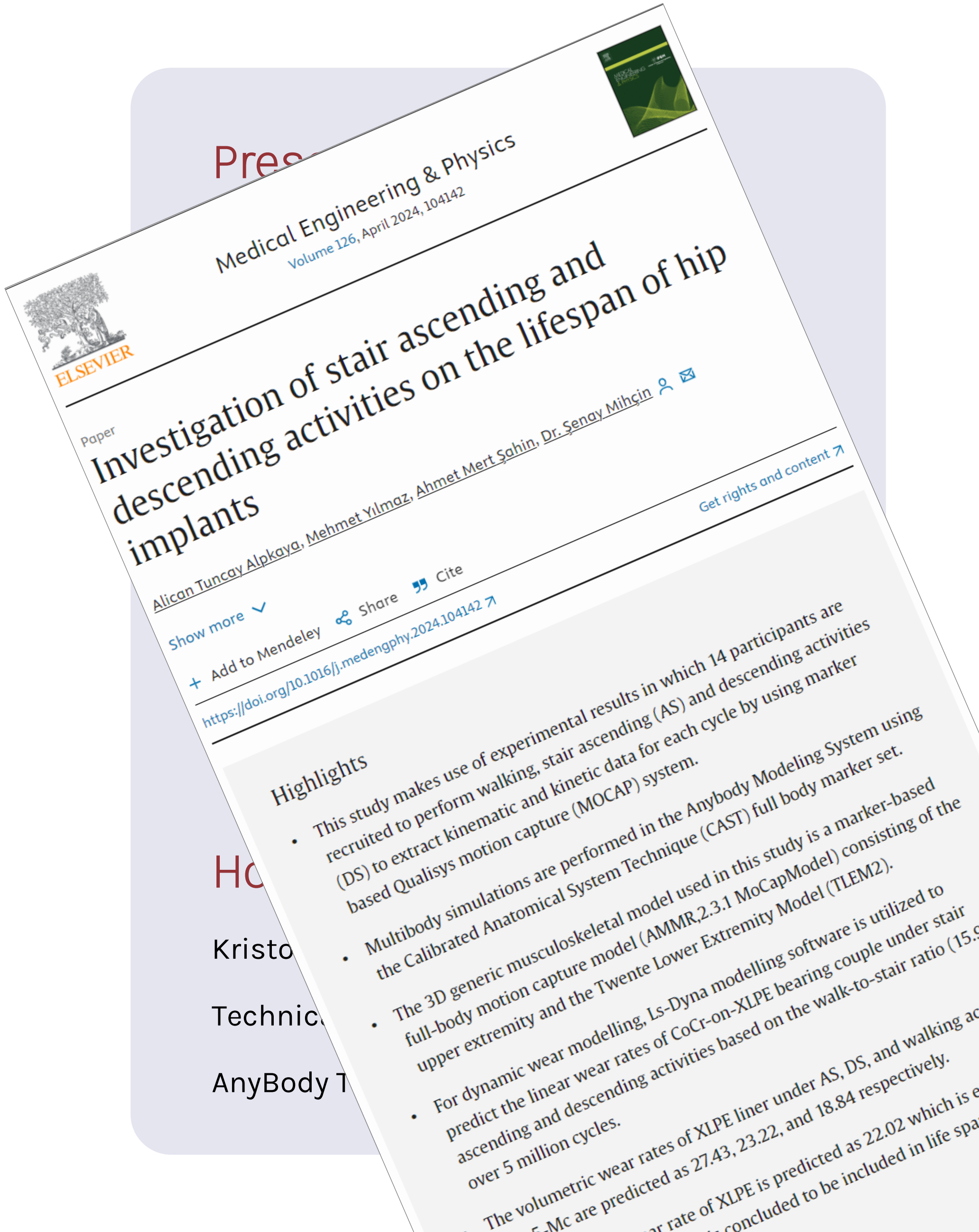
Pres

Ho

Kristo

Technic

AnyBody T



Control Panel

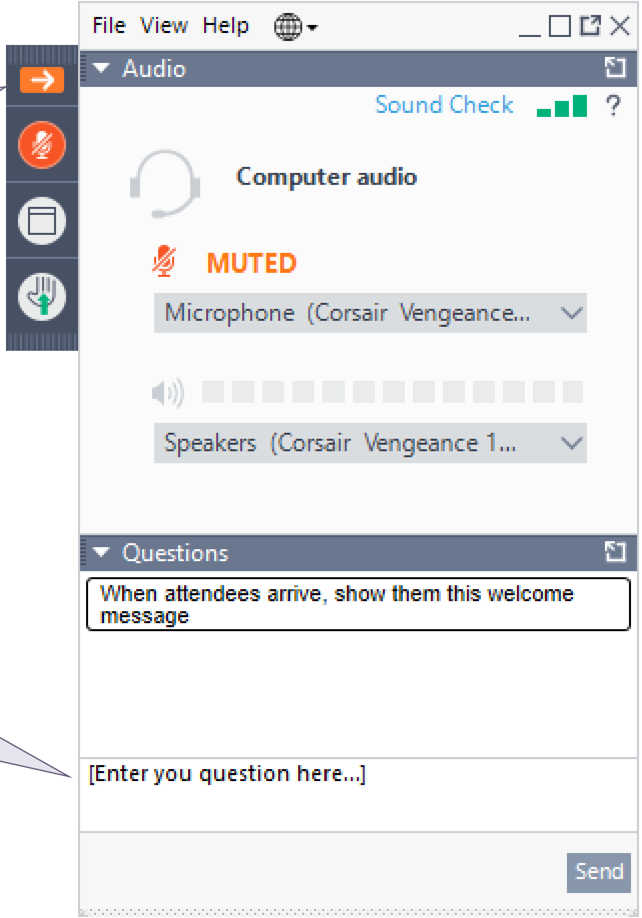
Expand/Collapse the Control Panel

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.

Ask a question during the presentation



Musculoskeletal simulations

INPUT • Motion data

- Motion
- Forces

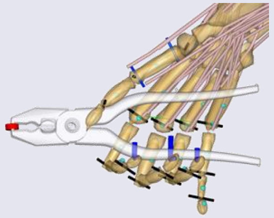
→ AnyBody Modeling System →

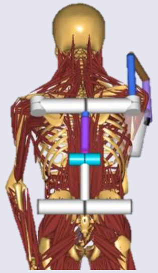
OUTPUT • Internal Body Loads

- Joint reaction forces
- Muscle forces
- Muscle activity
- Metabolic energy

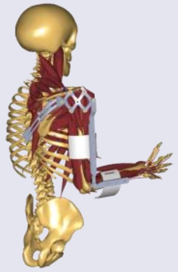
Motion analysis

Product design and optimization

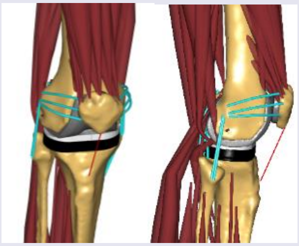




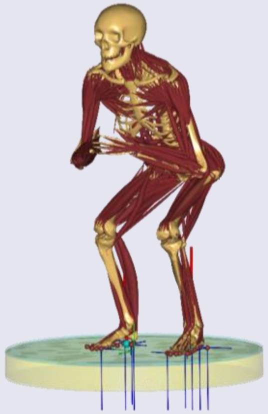
Ergonomics with/without exoskeletons



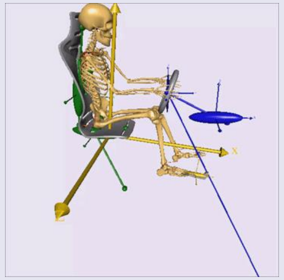
ANYBODY MODELING SYSTEM



Orthopedics and Rehabilitation



Sports

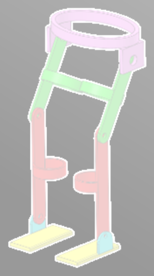


Automotive

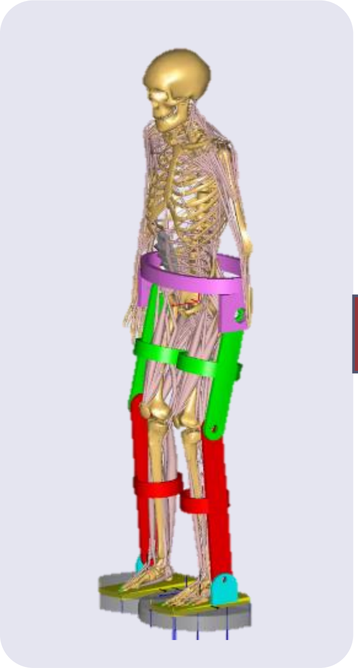
Workflow

Motions and forces

Body model

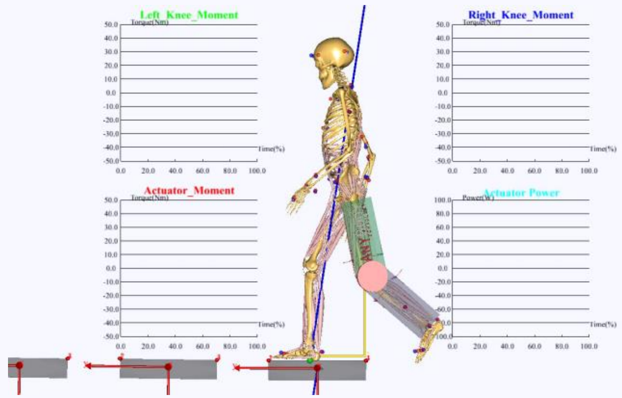


Environment model



Simulation

Inverse dynamics
Muscle recruitment



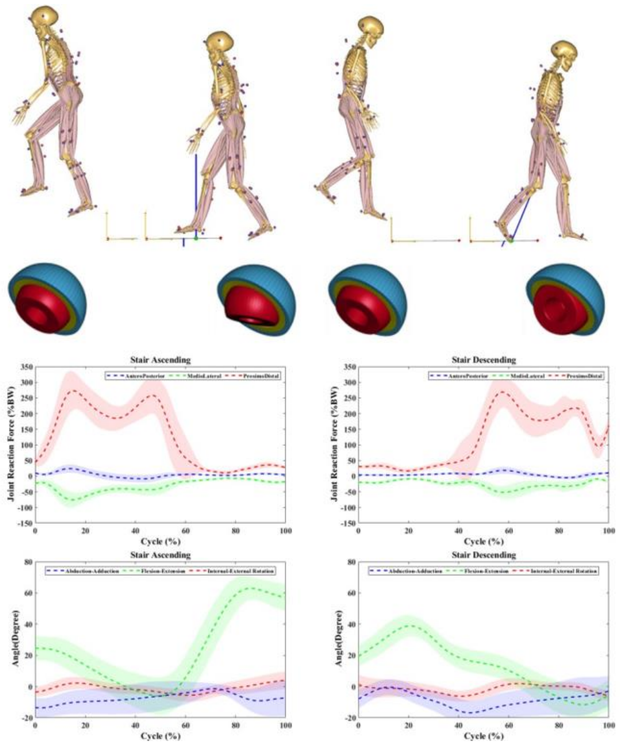
Internal body loads:

- Muscle forces
- Joint forces

Design Optimization

Post Processing
(e.g. Finite Element tools)

Investigation of stair ascending and descending activities on the lifespan of hip implants



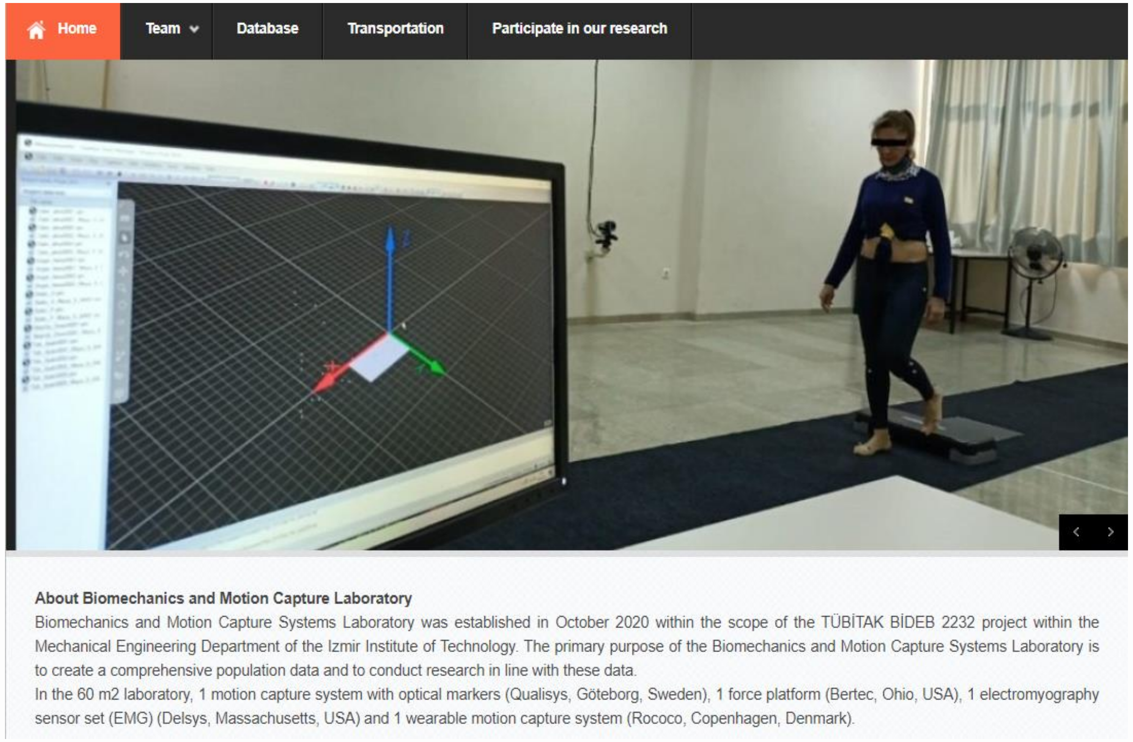
Investigation of stair ascending and descending activities on the lifespan of hip implants

Authors and Presenters

S. Mihcin , A. M Sahin , M. Yılmaz ,A. T. Alpkaya,

IZMIR INSTITUTE OF TECHNOLOGY (IZTECH)

IZTECH Biomechanics and Motion Capture Laboratory



Name	Label	Number
Motion capture system with optical markers	Qualisys, Göteborg, Sweden	1
Miqus 3 Cameras	Qualisys, Göteborg, Sweden	9
Qualisys Track Manager	Qualisys, Göteborg, Sweden	1
14 mm reflective markes	Qualisys, Göteborg, Sweden	100
Force platform	Bertec, Ohio, USA	1
Electromyography sensor set (EMG)	Delsys, Massachusetts, USA	1
Wearable motion capture system	Rococo, Copenhagen, Denmark	1
Hip simulator	IZTECH Biomechanics and Motion Capture Laboratory, Izmir,Turkey	1
3D medical PEEK printer	Xi'an Jiaotong University, Shaanxi, China	1
Anybody Modeling System	AnyBody Technology, Aalborg, Denmark	2
WorkStation (Intel Xeon W-2245)	4	4

Website: https://biomechlab.iyte.edu.tr/en/homepage/

Contact mail: senaymihcin@iyte.edu.tr

IZTECH Biomechanics and Motion Capture Laboratory

People	Assoc Prof Dr. Şenay Mihçin	MSc. Alican Tuncay ALPKAYA	Mehmet Yılmaz	Ahmet Mert Şahin
Role	Team Leader	Researcher Assistant	Researcher	Researcher
Degree	Ph.D.	MSc.	BSc	BSc
University	Loughborough University	Middle East Technical University	Erciyes University	Izmir Institute of Technology
Year	2008	2018	2021	2021

Journal Publications

[1] S. Mihcin *et al.*, "Database covering the prayer movements which were not available previously," *Scientific Data*, vol. 10, no. 1, p. 276, 2023, doi: 10.1038/s41597-023-02196-x.

[2] A. T. Alpkaya and Ş. Mihçin, "The Computational Approach to Predicting Wear: Comparison of Wear Performance of CFR-PEEK and XLPE Liners in Total Hip Replacement," *Tribology Transactions*, vol. 66, no. 1, pp. 59–72, 2023, doi: 10.1080/10402004.2022.2140727.

[3] A. T. Alpkaya and S. Mihcin, "Dynamic computational wear model of PEEK-on-XLPE bearing couple in total hip replacements," *Medical Engineering & Physics*, p. 104006, 2023, doi: https://doi.org/10.1016/j.medengphy.2023.104006.

[4] A. T. Alpkaya, M. Yılmaz, A. M Sahin, and S Mihcin, "Investigation of stair ascending and descending activities on the lifespan of hip implants," vol. 126, 2024, doi: 10.1016/j.medengphy.2024.104142.

[5] S.Mihcin, Simultaneous validation of wearable motion capture system for lower body applications: over single plane range of motion (ROM) and gait activities, BIOMEDICAL ENGINEERING-BIOMEDIZINISCHE TECHNIK, 2022, 0013-5585, 67, 3, 185-199.

[6] Torabnia, **S., Mihcin,** S. & Lazoglu, I. Design and manufacturing of a hip joint motion simulator with a novel modular design approach. *Int J Interact Des Manuf* (2023). https://doi.org/10.1007/s12008-023-01506-2

Medical Engineering and Physics 126 (2024) 104142

Contents lists available at ScienceDirect

ELSEVIER

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Paper

Investigation of stair ascending and descending activities on the lifespan of hip implants

Alican Tuncay Alpkaya, Mehmet Yılmaz, Ahmet Mert Şahin, Dr. Şenay Mihçin *

Mechanical Engineering Department, Izmir Institute of Technology, Turkey

ARTICLE INFO

Keywords:
Dynamic wear predict model
Finite element model
Stair ascending and descending
Total hip replacement

ABSTRACT

Total hip arthroplasty (THA) surgeries among young patients are on the increase, so it is crucial to predict the lifespan of hip implants correctly and produce solutions to improve longevity. Current implants are designed and tested against walking conditions to predict the wear rates. However, it would be reasonable to include the additional effects of other daily life activities on wear rates to predict convergent results to clinical outputs. In this study, 14 participants are recruited to perform stair ascending (AS), descending (DS), and walking activities to obtain kinematic and kinetic data for each cycle using marker based Qualisys motion capture (MOCAP) system. AnyBody Modeling System using the Calibrated Anatomical System Technique (CAST) full body marker set are performed Multibody simulations. The 3D generic musculoskeletal model used in this study is a marker-based full-body motion capture model (AMMR,2.3.1 MoCapModel) consisting of the upper extremity and the Twente Lower Extremity Model (TLEM2). The dynamic wear prediction model detailing the intermittent and overall wear rates for CoCr-on-XLPE bearing couple is developed to investigate the wear mechanism under 3D loading for AS, DS, and walking activities over 5 million cycles (Mc) by using finite element modelling technique. The volumetric wear rates of XLPE liner under AS, DS, and walking activities over 5-Mc are predicted as 27.43, 23.22, and 18.84 mm^3/Mc respectively. Additionally, the wear rate was predicted by combining stair activities and gait cycles based on the walk-to-stair ratio. By adding the effect of stair activities, the volumetric wear rate of XLPE is predicted as 22.02 mm^3/Mc which is equivalent to 19.41% of walking. In conclusion, in this study, the effect of including other daily life activities is demonstrated and evidence is provided by matching them to the clinical data as opposed to simulator test results of implants under ISO 14242 boundary conditions.

Aims and Scope

Medical Engineering & Physics provides a forum for the publication of the latest developments in biomedical engineering, and reflects the essential multidisciplinary nature of the subject.

Journal information

MEDICAL ENGINEERING & PHYSICS

Publisher name: ELSEVIER SCI LTD

Journal Impact Factor ™

2.2	2.5
2022	Five Year

JCR Category	Category Rank	Category Quartile
ENGINEERING, BIOMEDICAL *in SCIE edition*	71/96	Q3

Source: Journal Citation Reports 2022. Learn more

Journal Citation Indicator ™

0.48	0.51
2022	2021

JCI Category	Category Rank	Category Quartile
ENGINEERING, BIOMEDICAL *in SCIE edition*	75/117	Q3

HIGHLIGHTS

- This study makes use of experimental results in which 14 participants are recruited to perform walking, stair ascending (AS) and descending activities (DS) to extract kinematic and kinetic data for each cycle by using marker based Qualisys motion capture (MOCAP) system.
- Multibody simulations are performed in the Anybody Modeling System using the Calibrated Anatomical System Technique (CAST) full body marker set.
- The 3D generic musculoskeletal model used in this study is a marker-based full-body motion capture model (AMMR,2.3.1 MoCapModel) consisting of the upper extremity and the Twente Lower Extremity Model (TLEM2).
- For dynamic wear modelling, Ls-Dyna modelling software is utilized to predict the linear wear rates of CoCr-on-XLPE bearing couple under stair ascending and descending activities based on the walk-to-stair ratio (15.9:1) over 5 million cycles.
- The volumetric wear rates of XLPE liner under AS, DS, and walking activities over 5-Mc are predicted as 27.43, 23.22, and 18.84 respectively.
- The volumetric wear rate of XLPE is predicted as 22.02 which is equivalent to 19.41% of walking, which is concluded to be included in life span estimations of implants for realistic outcomes.

OUTLINE

- Introduction
- Methodology
  - Participants
  - Construction of the Experiment
  - Data Acquisition
  - Musculoseletal Modelling
  - Finite Element Method
- Results
- Conclusion

IZTECH Biomechanics and Motion Capture Laboratory

Laboratory Environment

Lab Facilities

Name	Label	Number
Motion capture system with optical markers	Qualisys, Göteborg, Sweden	1
Miqus 3 Cameras	Qualisys, Göteborg, Sweden	9
Qualisys Track Manager	Qualisys, Göteborg, Sweden	1
14 mm reflective markes	Qualisys, Göteborg, Sweden	100
Force platform	Bertec, Ohio, USA	1
Electromyography sensor set (EMG)	Delsys, Massachusetts, USA	1

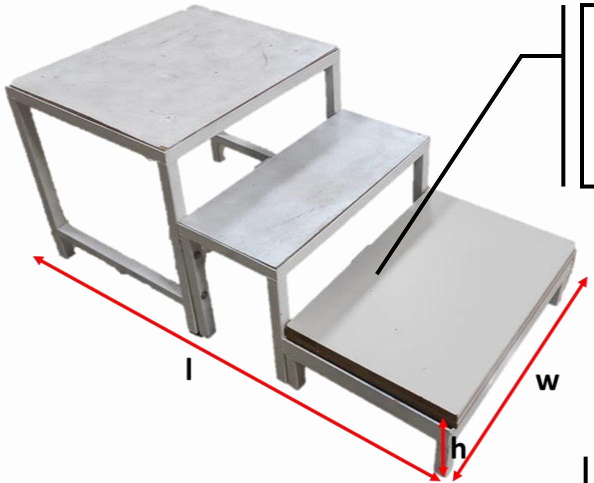
Construction of the Experiment

Qualysis Miqus Camera

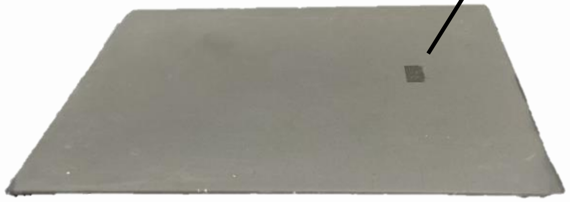
Capture rate:100 fps
Exposure & Flash Time[μs]:70
Marker Threshold[%]:20
Standard Deviation: Under 1mm

Marker

14 mm

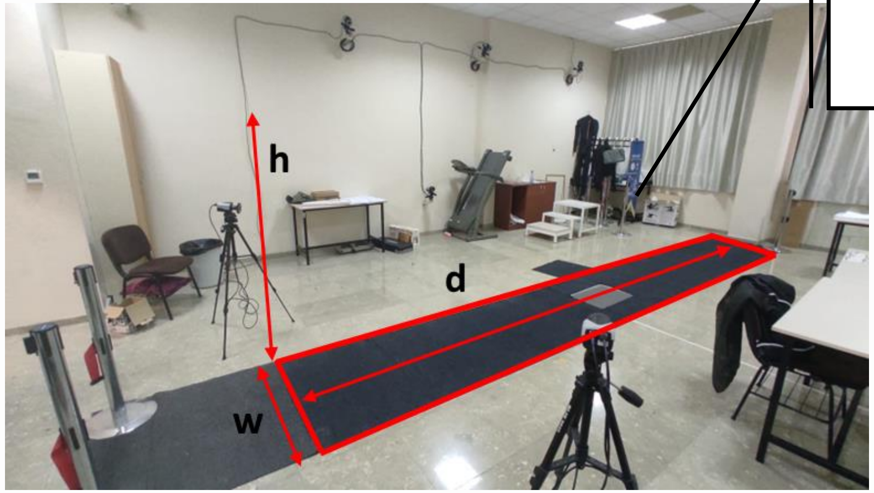


w: 61.8 cm
l: 119.2 cm
h: 16.4 cm



Bertec Force Plate

Capture rate:100 Hertz
Dimensions: 400x600mm
Channel Number: 6



d: 5 meter
w: 1 meter
h: 2 meter

Working volume

Data Acquisition

Data Acquisition (Participation and Measurement)

Participation Conditions

- not having any physical illness, injuries, disability and deformity (Flatfoot, kyphosis, etc.)
- Being over age of 18
- the body mass index must be below 30 BMI.

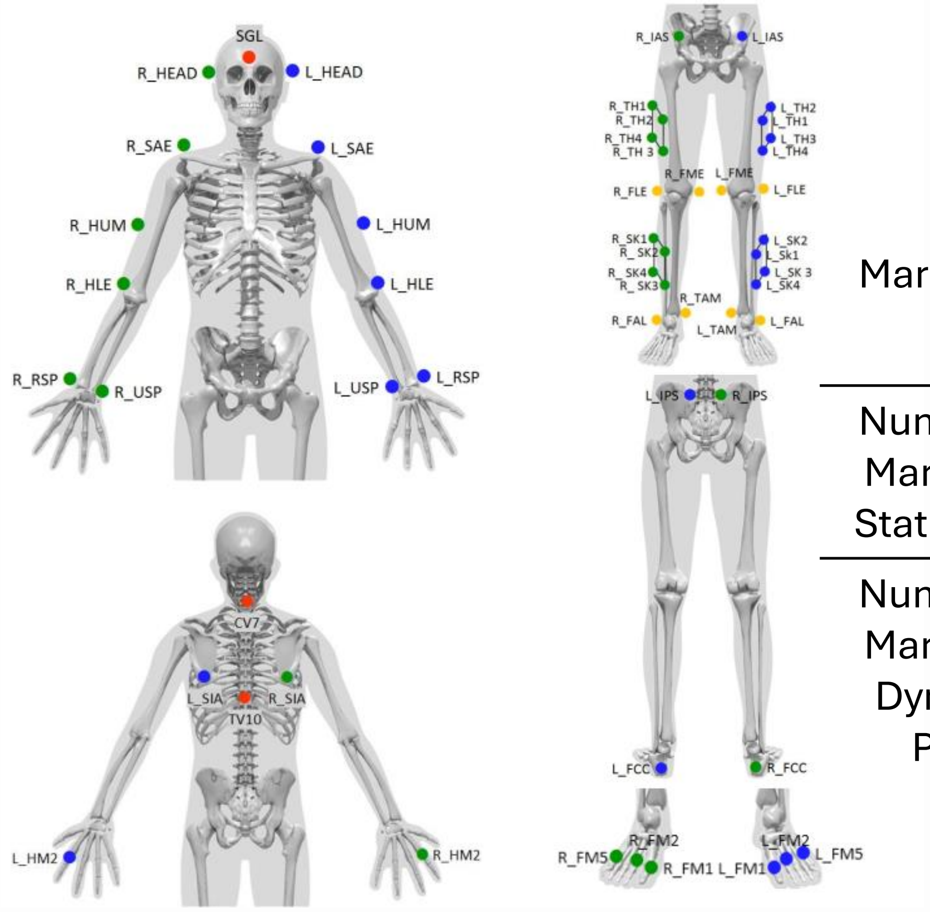
Participants

Participants Number	14(7F/7M)
Age	30±7
Weight(kg)(Average ±SD)	64±12
Height(cm)(Average ±SD)	170±11

Anthropometric Measurements

Anthropometric Measurements
Pelvis Medial Malleolus
Pelvis Width
Shank Length
Thigh Length
Foot Length
Metatarsal Width
Ankle Width
Knee Width
Trunk Height
Shoulder Width
Elbow Width
Hand Width
Wrist Width
Wrist Thickness
Upper Arm Length
Lower Arm Length
Arm length
Hand Length
Head Length

Data Acquisition (Marker Set)

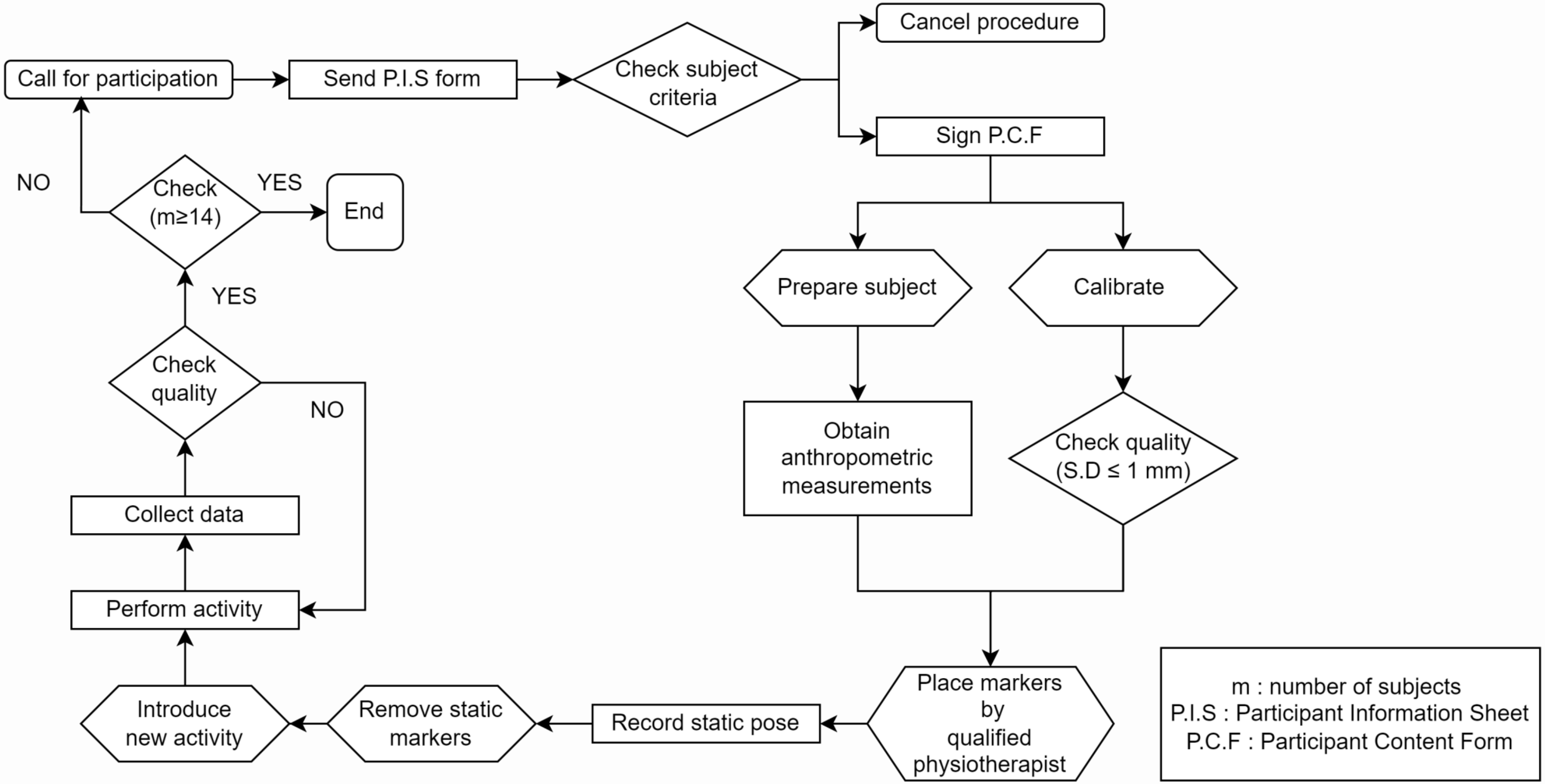


Cast Full Body Marker Set

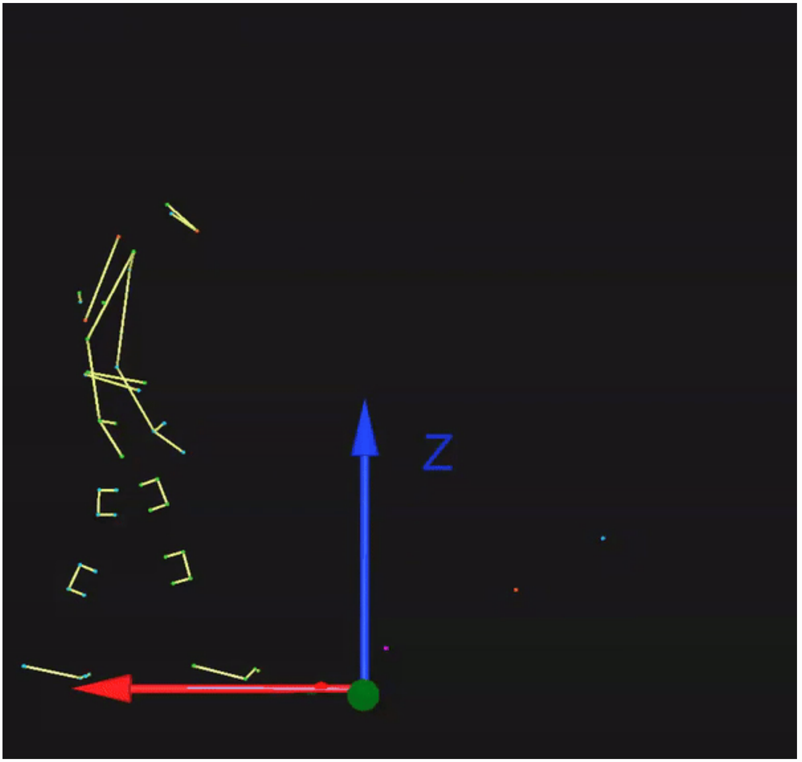
Marker Set	Cast Full Body Marker Set
Number of Marker for Static Pose	55
Number of Marker for Dynamic Pose	47

Participant

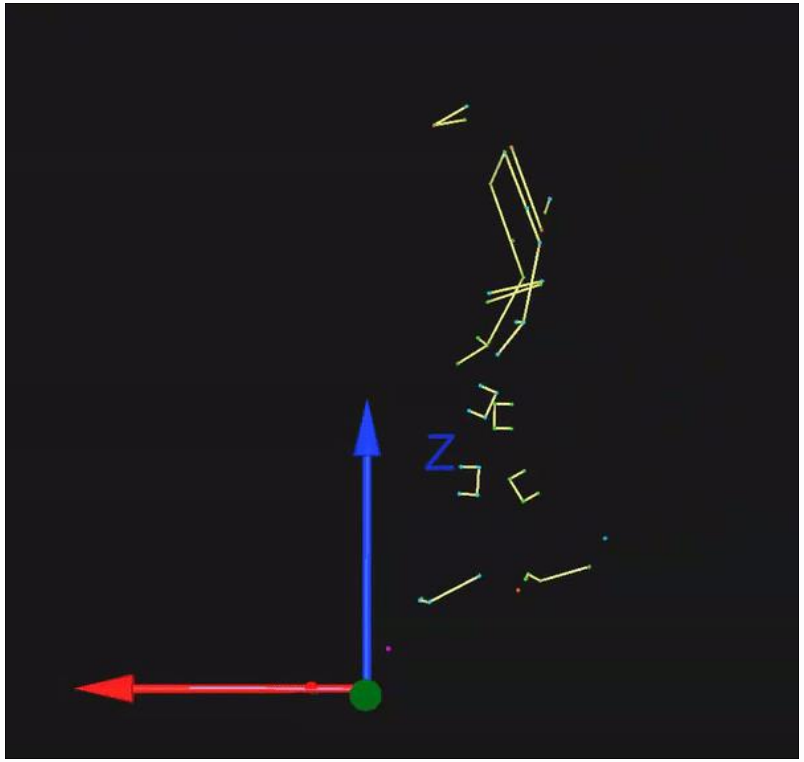
Data Acquisition Flow Chart



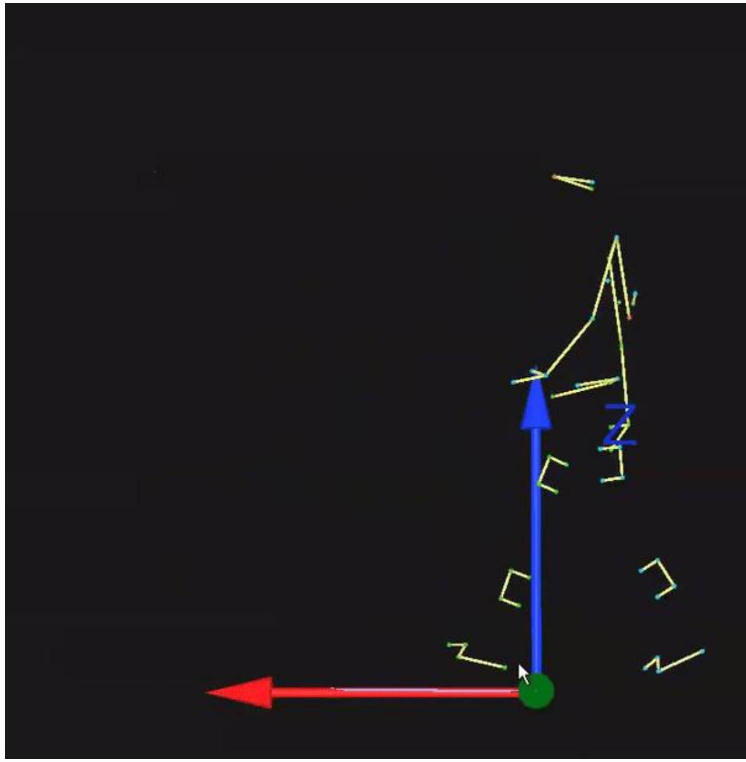
Activities



Stair
Ascending



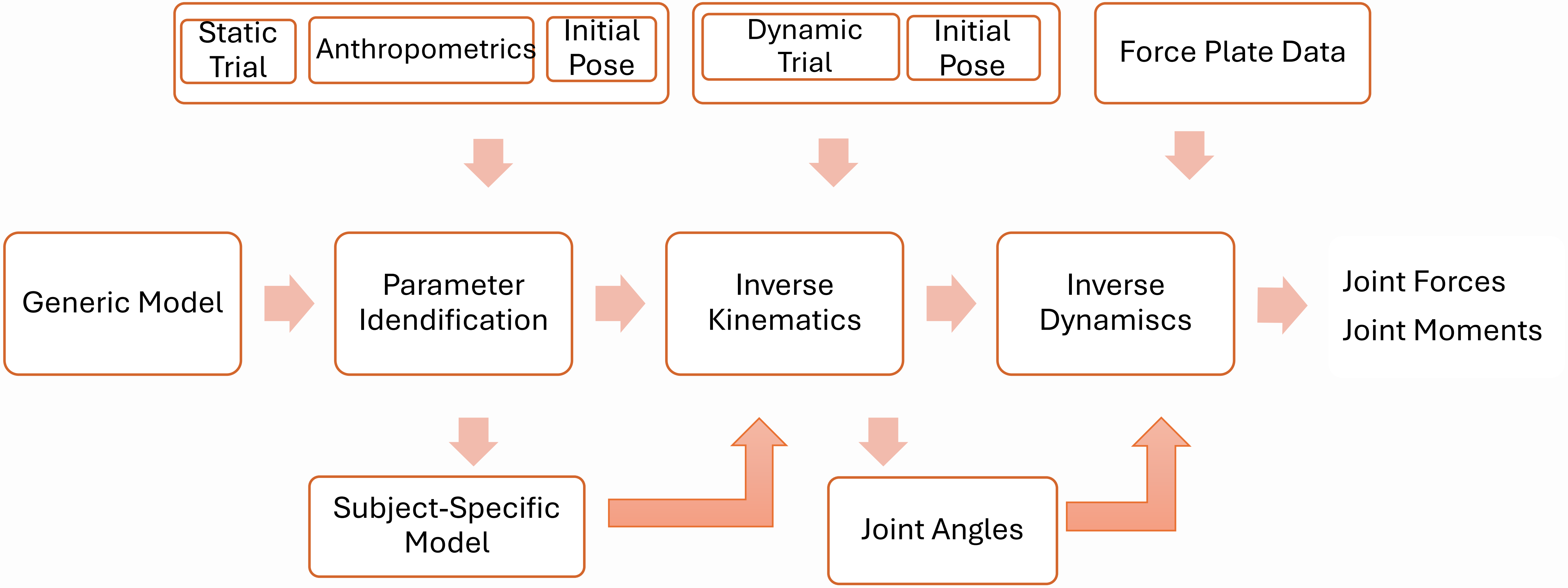
Stair
Descending



Gait

Multibody Musculoskeletal Model Simulations

Work Flow the Multibody Simulations in AnyBody



Full-Body MoCapModel Configurable Variables

- **Model**
  - Twente Lower Extremity Model (TLEM2)
- **Scaling**
  - Scale taking mass and fat into account; scale segments along X, Y, Z axes; input is scale factors along X, Y, Z axes.
- **Marker Protocol**
  - CAST Full Body Marker Set (Static&Dynamic)
- **Force Plate Type**
  - BERTEC force platform Type 4

Main.ModelSetup.LabSpecificData

- **Muscle Recruitment Optimization algorithms**
  - Third order, polynomial muscle recruitment criterion

Main.Studies.InverseDynamicStudy

- **Anthropometrics**
  - Set anthropometrics for each subject (mass, height,etc.)

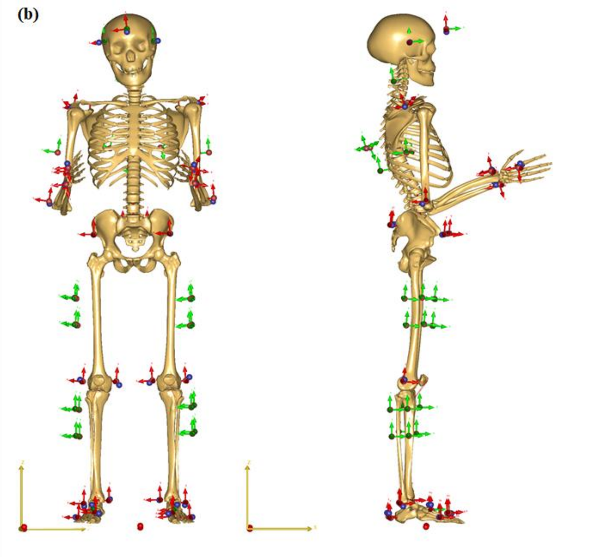
Main.ModelSetup.SubjectSpecificDa

- **Inital Position of Segments**
  - This sets load time limbs positions (Static&Dynamic)

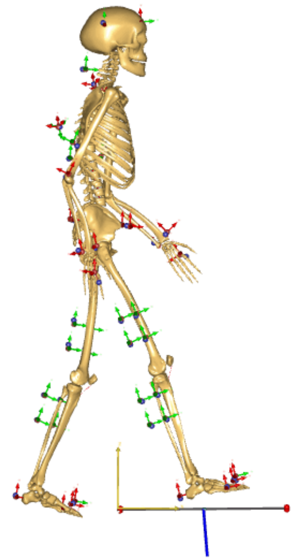
Main.ModelSetup.TrialSpecificData

Static and Dynamic Simulations

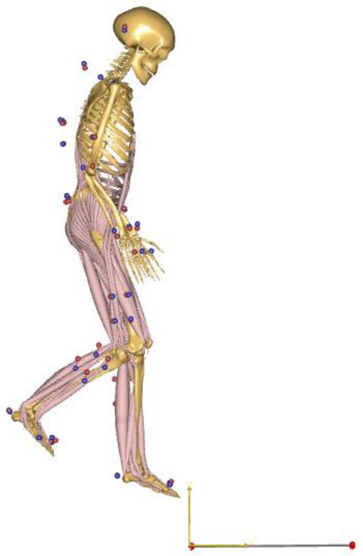
Static



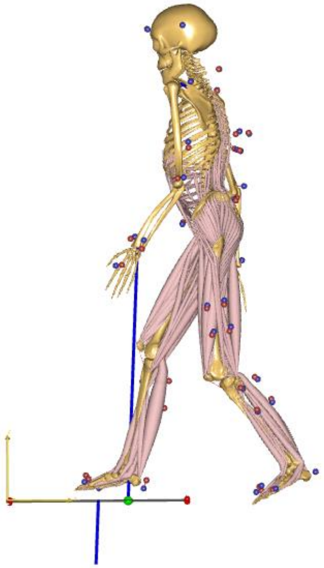
Gait



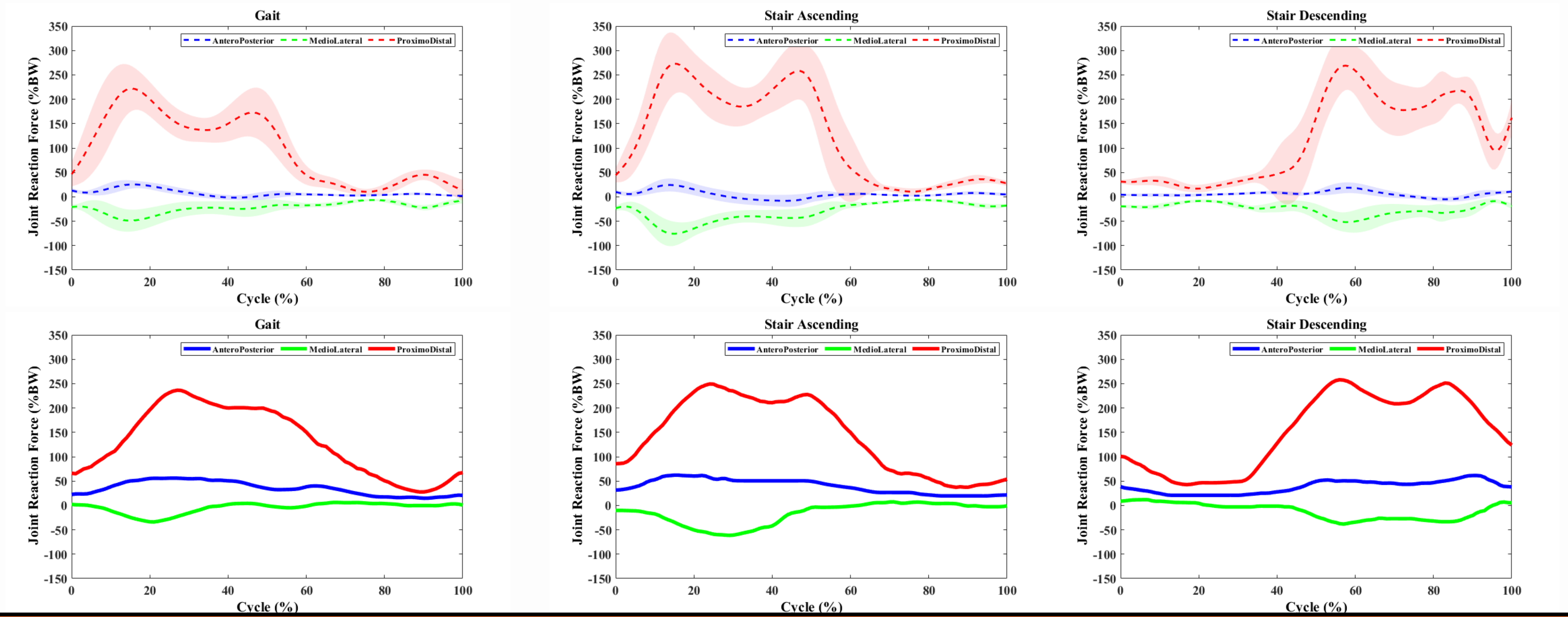
Stair Descending



Stair Ascending

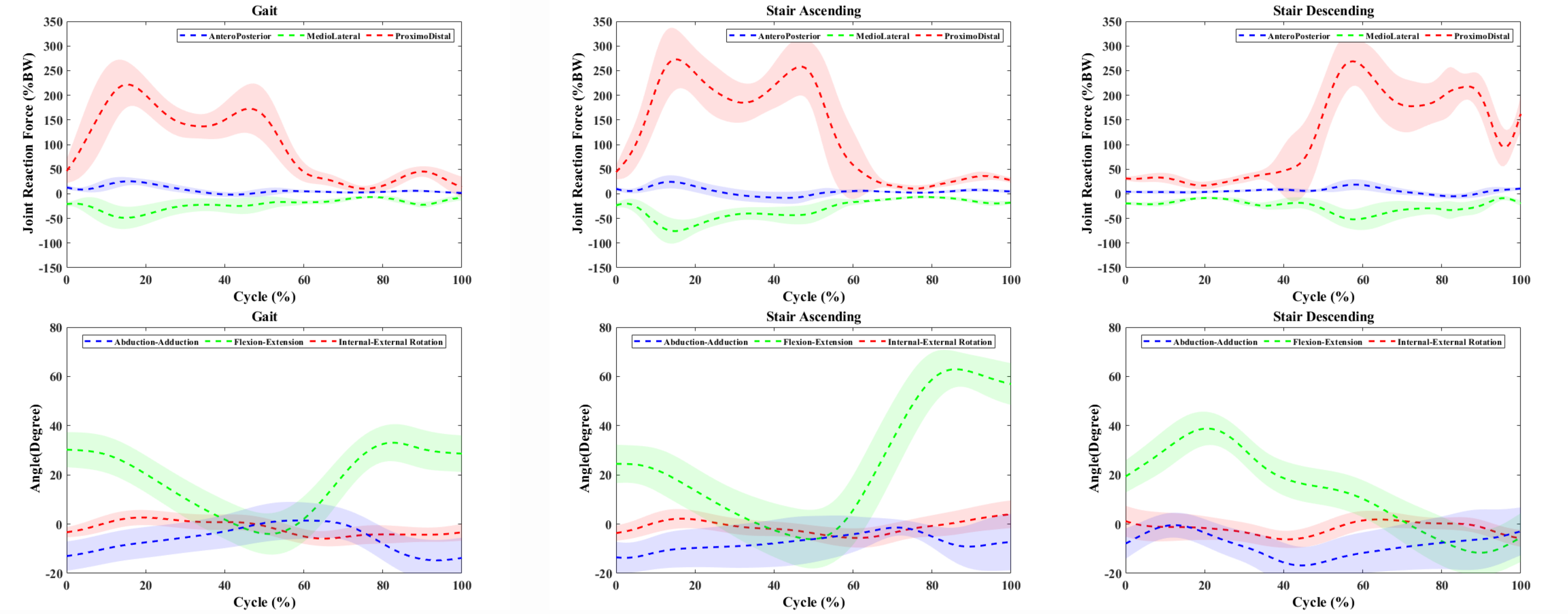


Validation



Activity	Calculated (%BW) Peak Hip Contact Force	Measured(%BW) Peak Hip Contact Force	(%)
Gait	221	238	%8 lower
Stair Ascending	272	251	%8 greater
Stair Descending	268	260	%3 greater

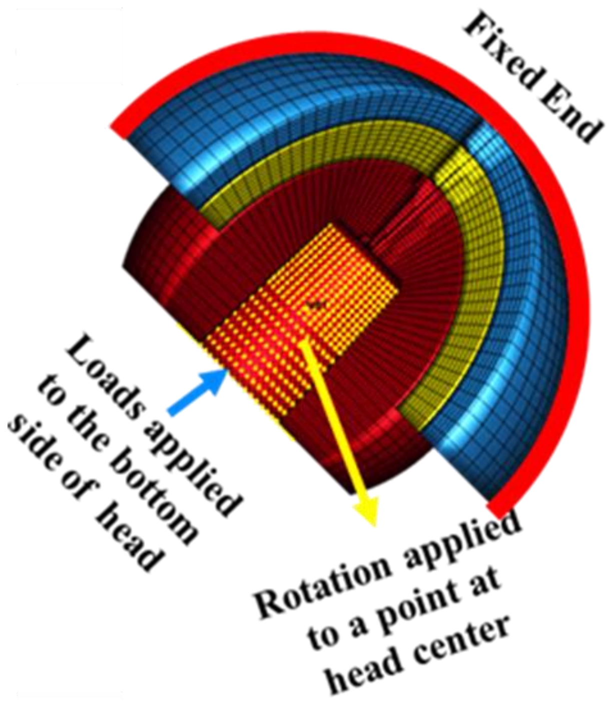
Results



Activity	ABD(°)Min/Max	FE(°)Min/Max	IE(°)Min/Max	AP(%BW)Min/Max	ML(%BW)Min/Max	PD(%BW)Min/Max
Gait	-6/3	**-3/33**	-14/2	-2/25	-48/-6	**10/221**
Stair Ascending	-5/4	**-6/63**	-13/-1	-8/24	-75/-6	**10/272**
Stair Descending	-6/2	**-11/38**	-16/-1	-5/18	-51/-8	**17/268**

Finite Element Modelling for Wear Analysis

The hypothesis



1

Literature Data

- ✓ The lifespan of hip implant under walking cycles in FEM could be predicted as 25.7 years [11]
- ✓ J.T. Evans et al studied at the lifespan of 228888 hip implants in 16 different countries [63]. The average lifespan of hip implants last 20 years [63]

2

The hypothesis

The daily frequency of stair ascending/descending per day is calculated as

- ✓ 172 cycles which is equivalent to 62780 cycles for stair ascending/descending
- ✓ 3040 steps per day which is equivalent to 1 Mc per year
- ✓ Predicted the walk-to-stair ratio of 15.9:1

3

Wear Prediction Model

- ✓ We investigate the wear performance and longevity of hip implants adding stair ascending and stair descending wear rates on walking cycles according to the walk-to-stair ratio provided to converge our results with literature data

Model Quality

Pre-analysis

Mesh
- Type
- Order
- Section

B.C and L.C
- Constrain
- Load
- Motion

Cont. Types
- Tied
- Surface to Surface

Mat. Prop.
- Mat-001
- Cof
- Archard W.

Analysis

Sens. Analys.
- Mesh Size
- Scaling Factor

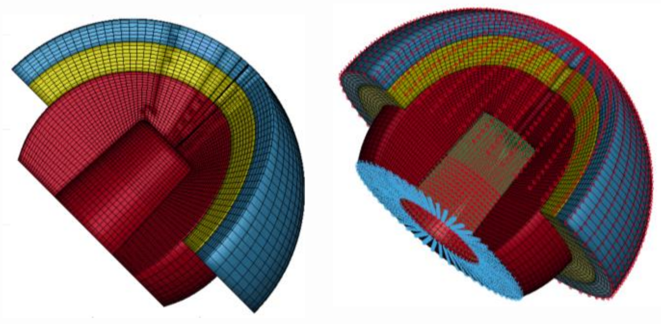
Solver
- Ls-Dyna
  - Shared parallel memory (SMP)
  - Double Precision

Post-analysis

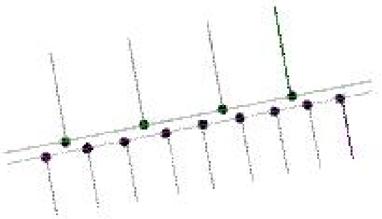
Results Proces.
- Wear rate
- Sliding D.
- Contact P.
- Contact A.

Validatio n
- Hip simulator
- Clinical Retrieval
- Fem Results

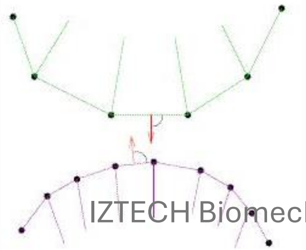
Report

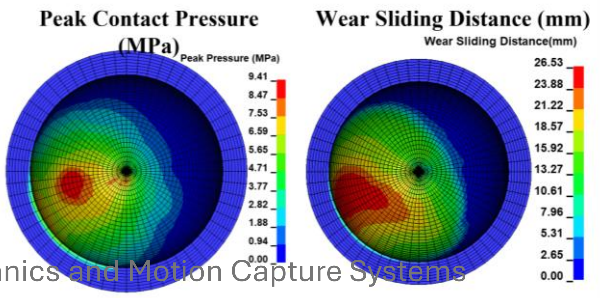


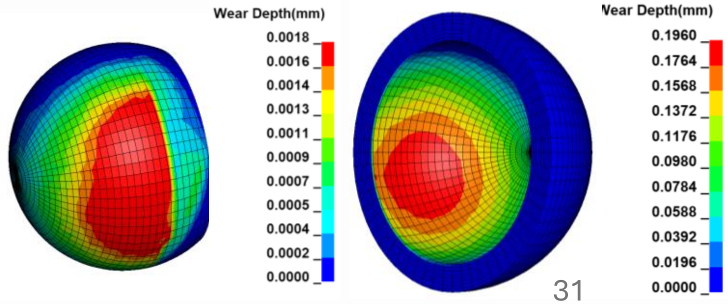
Tied Contact



Surface to Surface Contact







Material and Methods

- ✓ An explicit FE analysis tool (Ls-Dyna R.12.0) over 5 million cycles.
- ✓ The liner inserted at 45^0 on the FE axis.
- ✓ The shell is fixed, while the femoral head is free.
- ✓ The loading is applied, while the rotations are defined.

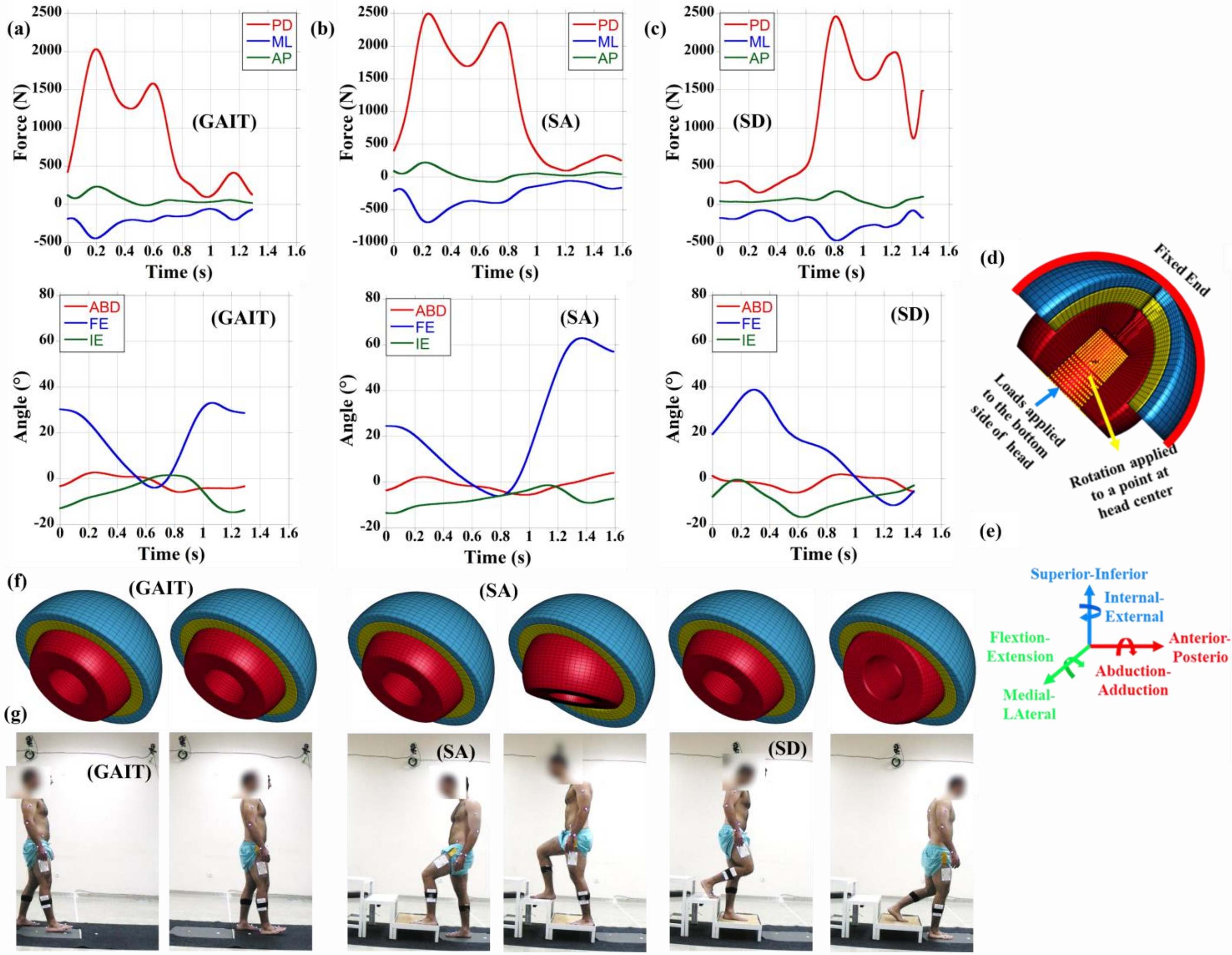


Figure 1 The loading and rotation data for (a) gait, (b) SA, (c) SD, d) applied loading and boundary conditions in FEM, (e) loading and rotation in anatomical axes, and (f) initial and final position in FEM, and (g) initial and middle position of each activity.

Mesh Sensivity Analysis

- ✓ Mesh convergence test is a vital process.
- ✓ Variations in the outputs are less than 1%, the optimum mesh size is determined.
- ✓ Seven CoCr-on-XLPE prototypes were modelled.
- ✓ The optimum mesh will be selected as 1mm

Figure 2 a) Mesh sensitivity analysis of CoCr-on-XLPE bearing couple and b) Peak contact pressure and wear sliding distance results of the prototypes with 1- and 1.6-mm element size

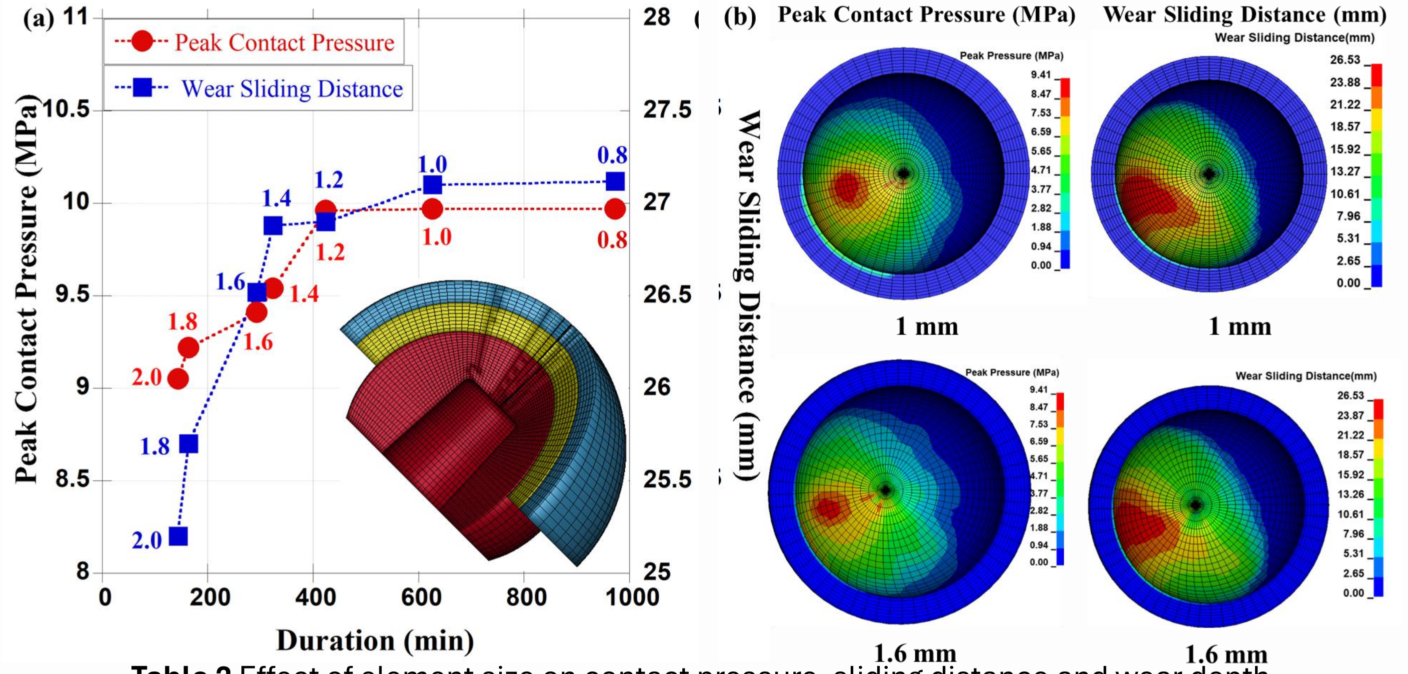
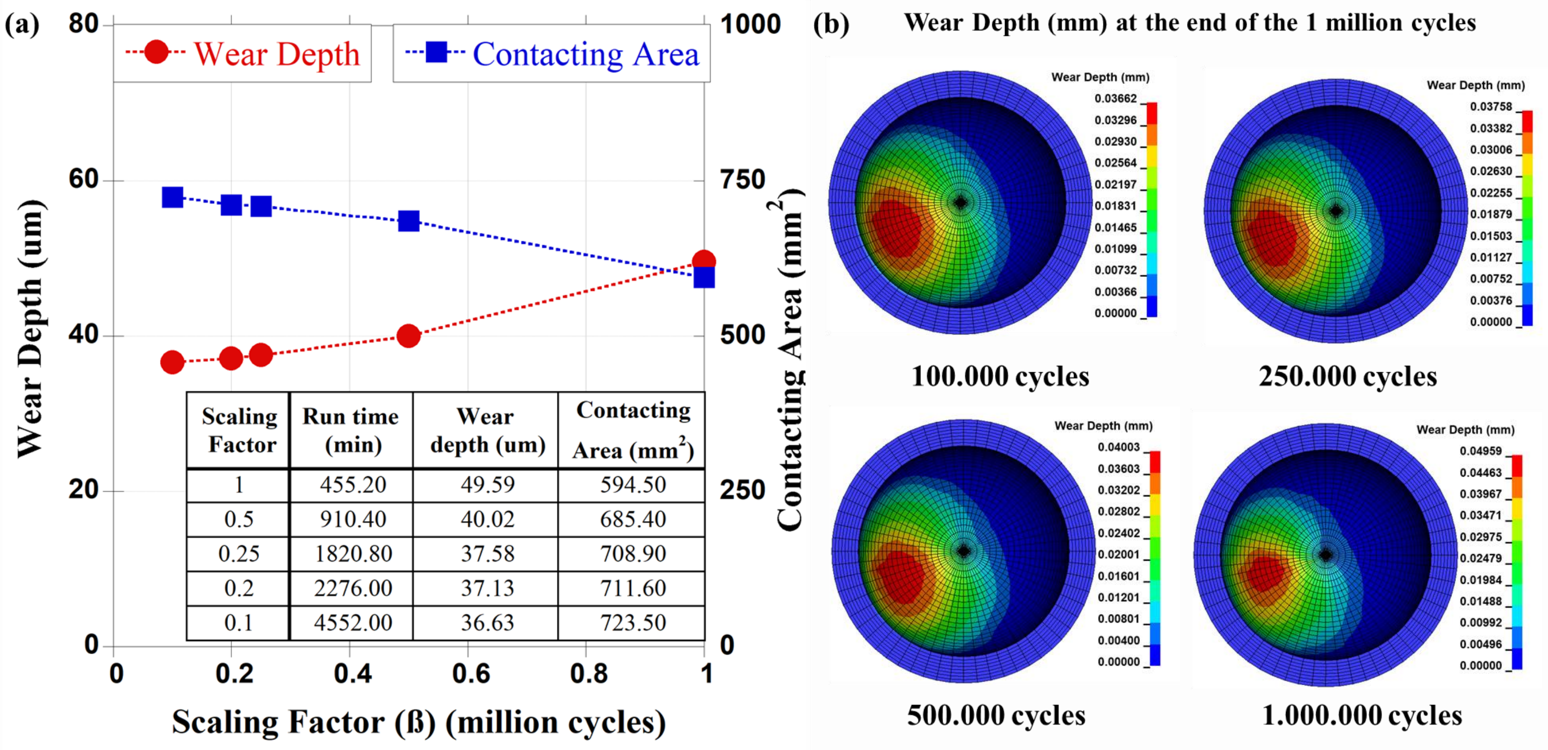


Table 2 Effect of element size on contact pressure, sliding distance and wear depth

El. Size (mm)	Run (min)	C. P. (MPa)	C.P (%)	W. D. (10^{-8}mm)	W.D. (%)	S.D. (mm)	S.D. (%)	Liner Element
2.00	144	9.05	1.90	4.43	6.54	25.20	1.95	7200
1.80	164	9.22	2.05	4.74	3.46	25.70	3.09	8160
1.60	293	9.41	1.31	4.91	0.81	26.52	1.34	9120
1.40	324	9.54	4.27	4.95	0.80	26.88	0.07	10560
1.20	424	9.96	**0.04**	4.99	3.48	26.90	**0.74**	12480
1.00	**627**	**9.97**	**0.03**	**5.17**	**0.19**	**27.10**	**0.57**	**14880**
0.80	973	9.97	-	5.18	-	27.25	-	18720

Scaling Factor Sensivitiy Analysis

- ✓ The scaling factor *(β)* has a major impact.
- ✓ Ranged from *0.1* to *1* million cycles
- ✓ The run time of the model with *0.25* million cycles is approximately *2.5* times higher than the model with *0.1* million cycles.
- ✓ The optimum scaling factor is selected as *0.25* million cycles (Figure 3a).



Scaling Factor	Run time (min)	Wear depth (um)	Contacting Area (mm²)
1	455.20	49.59	594.50
0.5	910.40	40.02	685.40
0.25	1820.80	37.58	708.90
0.2	2276.00	37.13	711.60
0.1	4552.00	36.63	723.50

Figure 3(a) The effect of scaling factor on wear depth and contacting area, and (b) wear depth at the end of the 1 million cycles

Results and Conclusion

Contact Pressure

The peak contact pressure values have obtained

- 6.33 MPa for gait at 0.21 s.
- 7.58 MPa for SD at 0.78 s.
- 8.33 MPa for SA at 0.23 s.

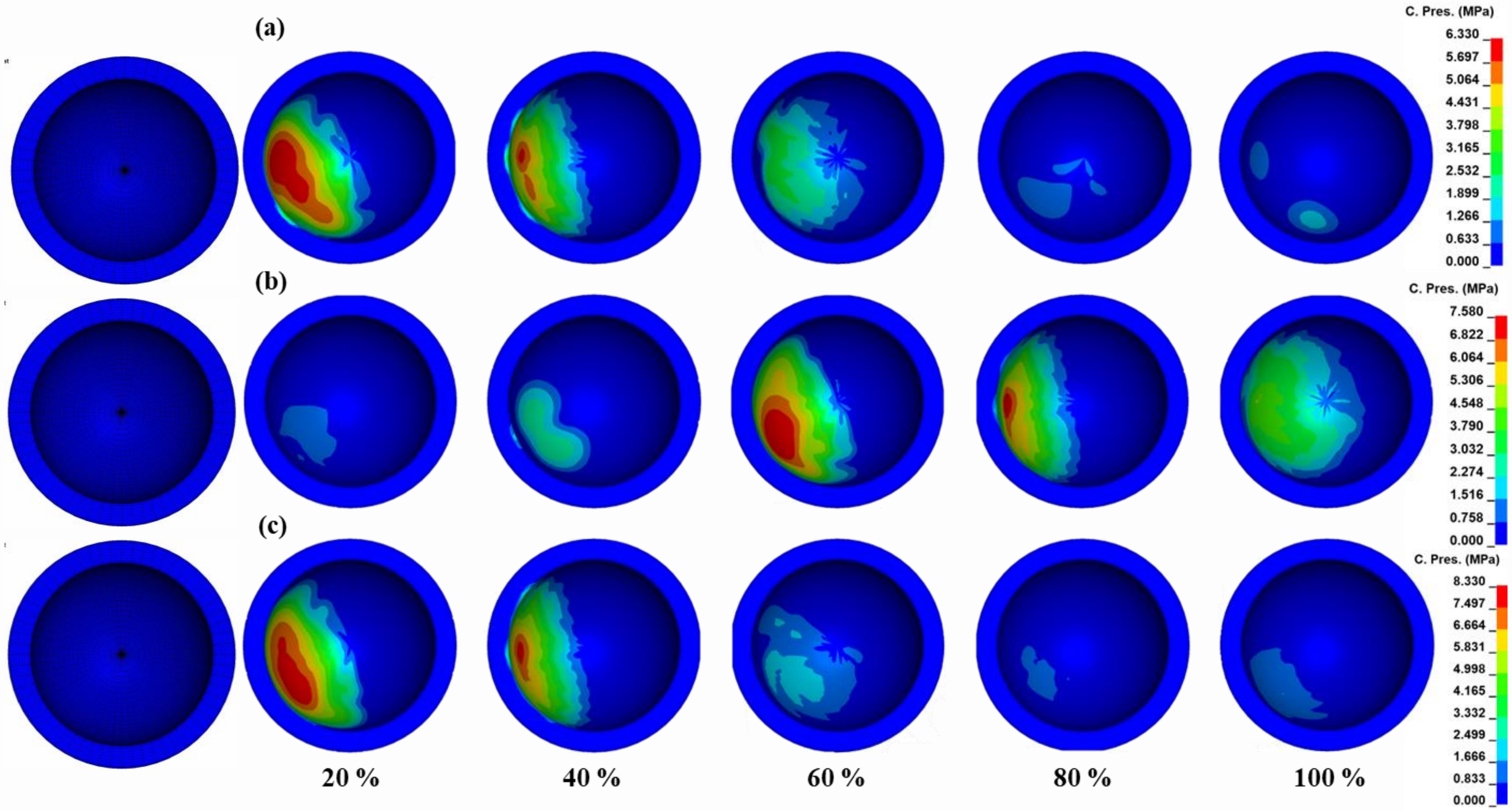


Figure 4 The contact pressure distribution over percentage of (a) gait, (b) SD, and (c) SA activities cycles at the end of the 250.000 cycles

Linear Wear Depth

Figure 5 shows the cumulative linear wear depth

- ✓ 0.14399 mm for gait (Figure 4a),
- ✓ 0.19599 mm for stair ascending (Figure 4b)
- ✓ 0.17936 mm for stair descending (Figure 4c)

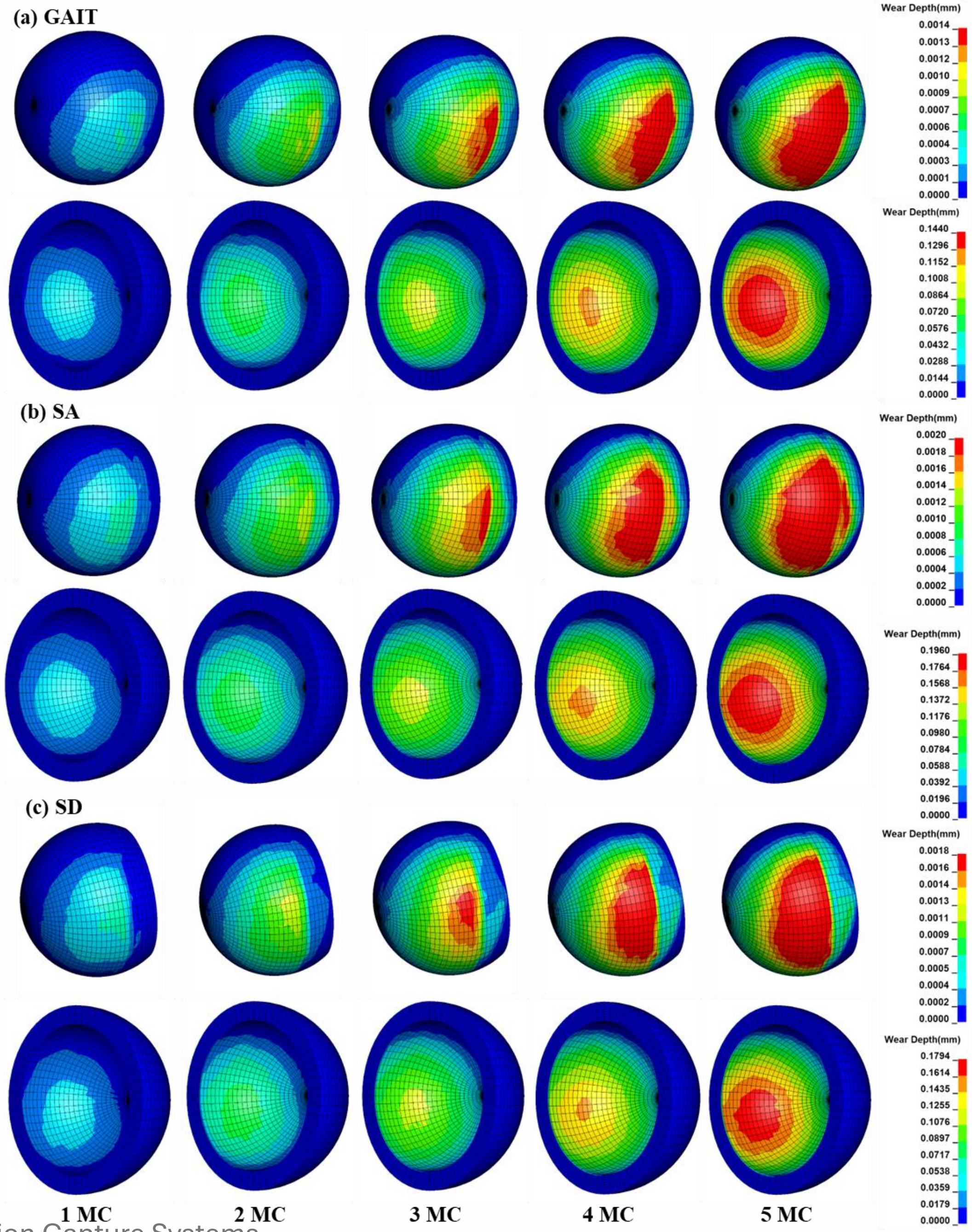


Figure 5 The linear wear depths of the femoral head and bearing liner under (a)gait, (b)SA, and (c)SD loading cycles at each specific cycle.

Linear Wear Depth And Volumetric Wear Loss

The percentage increases in mean volumetric wear rates of XLPE liner and CoCr head for gait (by adding SA and SD) activity compared to normal walking are predicted at

- 6.88% for XLPE liner
- 12.02% for CoCr head

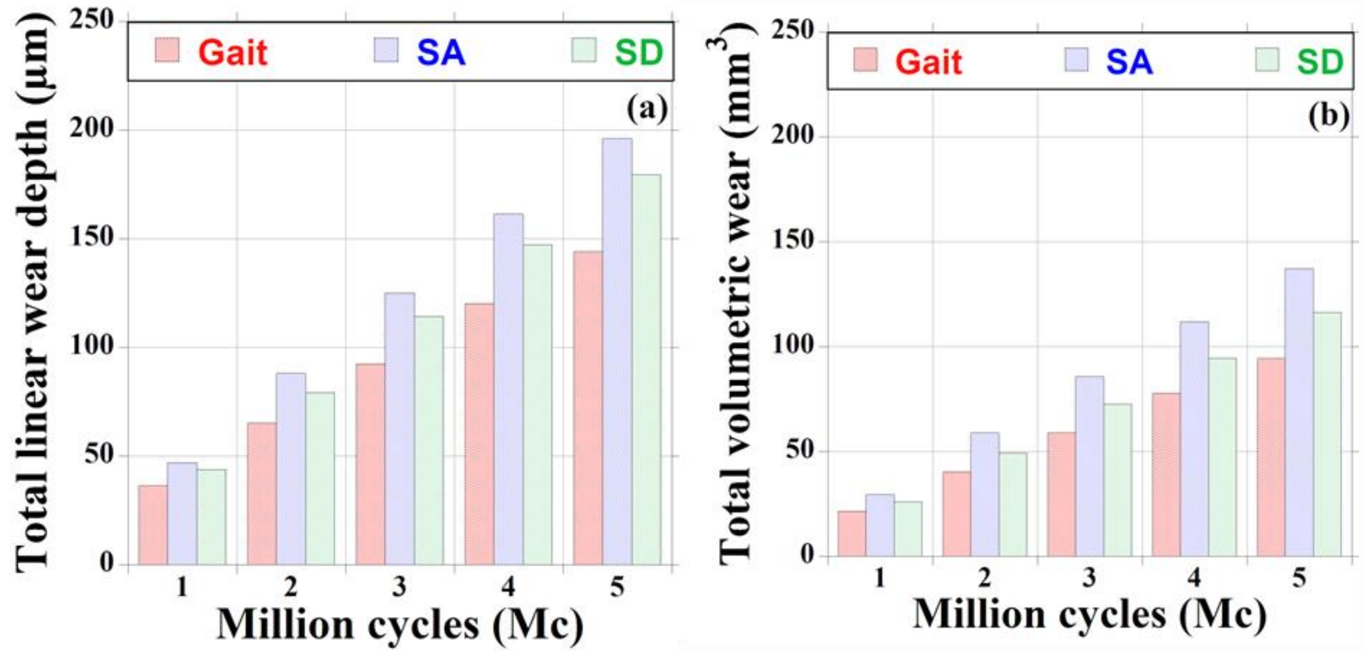


Figure 6 (a) Total linear wear depth and (b) total volumetric wear of XLPE bearing linear under gait, stair ascending and stair descending boundary conditions over five million cycles.

	Mean volumetric wear rate (mm^3/Mc)			
Part	**SA**	**SD**	**Gait**	**Gait (adding SA and SD)**
XLPE liner	27.429	23.220	18.839	22.020
CoCr head	0.337	0.307	0.336	0.376

Conclusion

- ✓ The volumetric wear rates of XLPE under walking increased by 16.9 % by including the effects of stair ascending/ descending activities.
- ✓ The linear wear rates of XLPE for walking increased up to 3.27% by adding stair ascending/descending activities.
- ✓ The lifespan of hip implant under walking cycles could be predicted as 25.7 years[11] in FEM and 20 years in clinical retrivial [63].
- ✓ In the current study, it could be predicted as 26.9 years for walking compared to 23 years with walking adding stair ascending and descending activities.
- ✓ While estimating the lifetime of the implants, the researchers should consider the cumulative effect of each daily life activity rather than focusing on only gait cycles for more accurate prediction of lifespan of hip implant.

References

- T. Karachalios, G. Komnos, and A. Koutalos, “Total hip arthroplasty: Survival and modes of failure,” *EFORT Open Rev.*, vol. 3, no. 5, pp. 232–239, 2018, doi: 10.1302/2058-5241.3.170068.
- J. G. Haw, A. K. Battenberg, D. C. T. Huang, and T. P. Schmalzried, “Wear Rates of Larger-Diameter Cross-Linked Polyethylene at 5 to 13 Years: Does Liner Thickness or Component Position Matter?,” *J. Arthroplasty*, vol. 32, no. 4, pp. 1381–1386, 2017, doi: 10.1016/j.arth.2016.11.022.
- M. Morlock *et al.*, “Duration and frequency of every day activities in total hip patients,” *J. Biomech.*, vol. 34, no. 7, pp. 873–881, 2001, doi: 10.1016/S0021-9290(01)00035-5.
- A. T. Alpkaya and S. Mihcin, “Dynamic computational wear model of PEEK-on-XLPE bearing couple in total hip replacements,” *Med. Eng. Phys.*, p. 104006, 2023, doi: https://doi.org/10.1016/j.medengphy.2023.104006.
- E. De Pieri, M. E. Lund, A. Gopalakrishnan, K. P. Rasmussen, D. E. Lunn, and S. J. Ferguson, “Refining muscle geometry and wrapping in the TLEM 2 model for improved hip contact force prediction,” *PLoS One*, vol. 13, no. 9, pp. 1–19, 2018, doi: 10.1371/journal.pone.0204109.
- G. Bergmann *et al.*, “Hip forces and gait patterns from rountine activities,” *J. Biomech.*, vol. 34, pp. 859–871, 2001.
- S. Mihcin *et al.*, “Database covering the prayer movements which were not available previously,” *Sci. Data*, vol. 10, no. 1, p. 276, 2023, doi: 10.1038/s41597-023-02196-x
- V. S. J. S, *Color Atlas of Skeletal Landmark Definitions: Guidelines for Reproducible Manual and Virtual Palpations*, vol. 4, no. 4. Churchill Livingstone/Elsevier, 2007. [Online]. Available: https://books.google.com.tr/books?id=fK_ZAQAACAAJ
- M. S. Andersen, M. Damsgaard, B. MacWilliams, and J. Rasmussen, “A computationally efficient optimisation-based method for parameter identification of kinematically determinate and over-determinate biomechanical systems,” *Comput. Methods Biomech. Biomed. Engin.*, vol. 13, no. 2, pp. 171–183, 2010, doi: 10.1080/10255840903067080.

Resources

- **www.anybodytech.com**
  - Events, Webcast library, Publication list, …
- **www.anyscript.org**
  - Wiki, Blog, Repositories, Forum
- **Events**
  - **June 4**: Webcast: New AnyBody Thoracic Spine, Ribcage and Abdominal Model
    - Registration is open on our website
  - **June 30 – July 4**: ESB 2024 – 29th Congress of the European Society of Biomechanics
  - **July 17 – 20**: SOA annual meeting 2024 – Southern Ortopaedic Association

1000+
publications

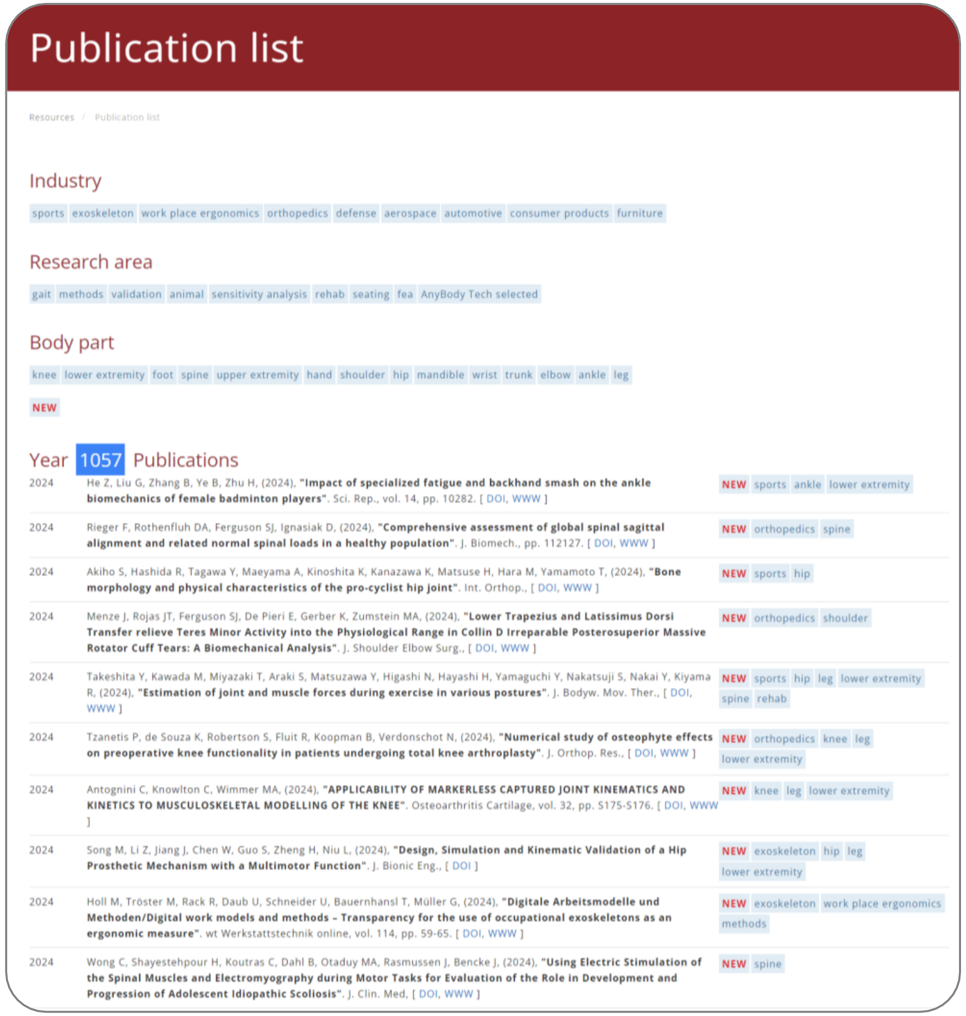
filter by:

- Industry
- Research area
- Body part

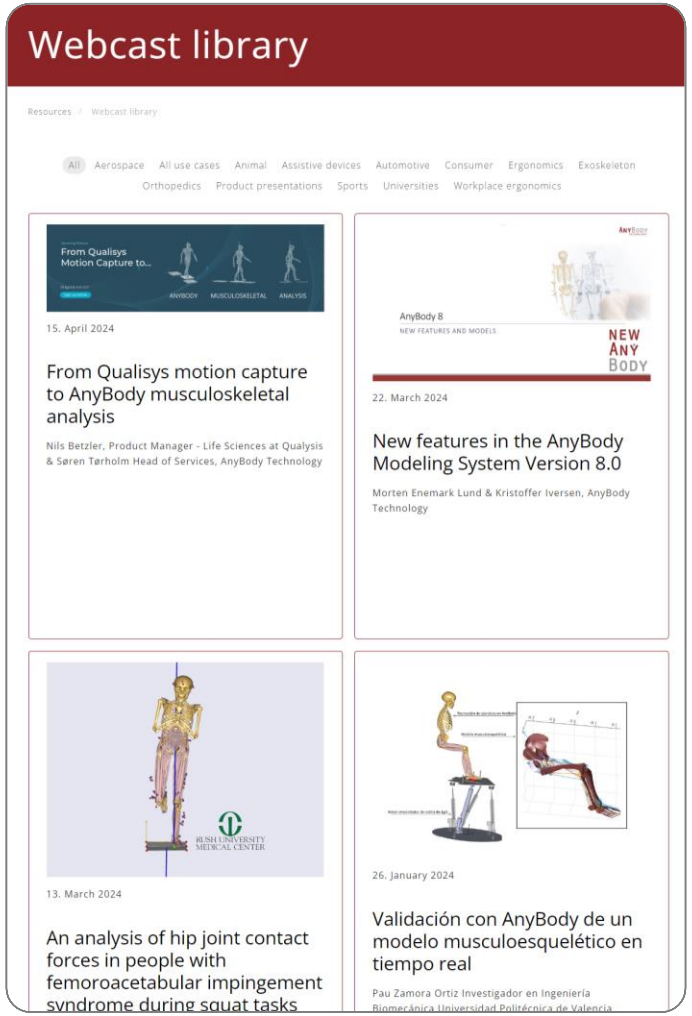
100+
webcasts

filter by:

- Industry



[Publications list](#)



[Webcasts list](#)

Questions

Meet us

- Send email to sales@anybodytech.com

Trial version

- Send email to sales@anybodytech.com

Presentation questions

- Send email to ki@anybodytech.com

Thank you for your attention!