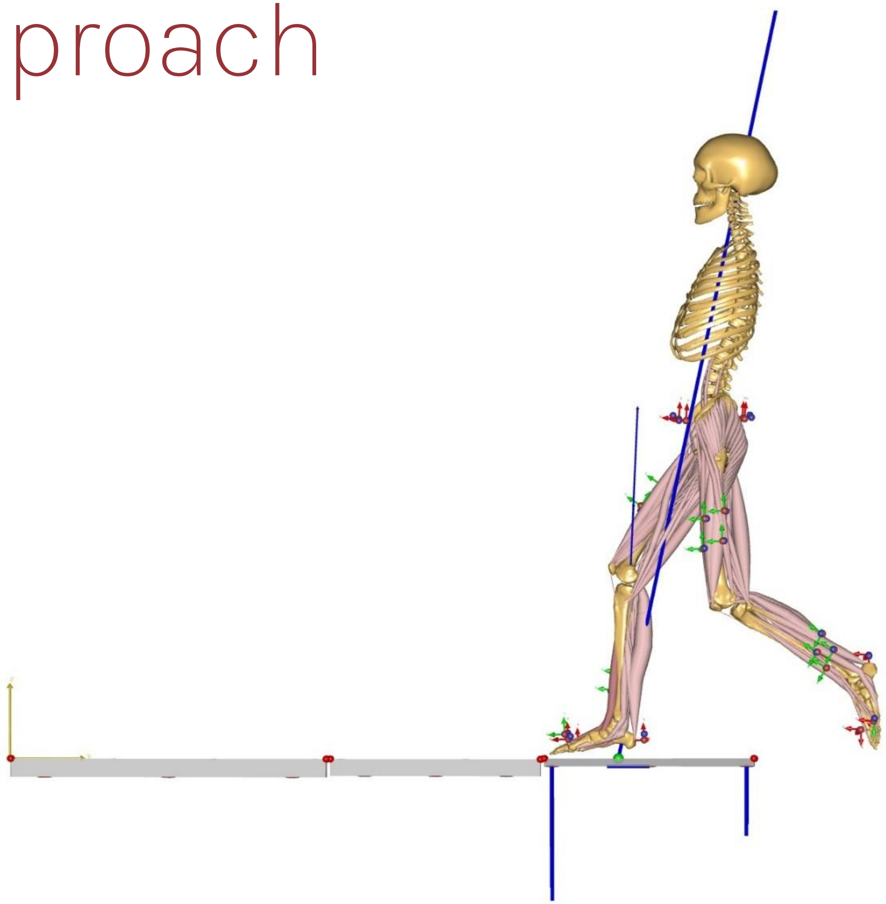
May 27, 2026

Age-related changes in the human musculoskeletal system: A modeling-based approach



The webcast will begin shortly...

Outline

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

Presenter

Katarzyna Nowakowska-Lipiec, Ph.D. Eng., Assistant Professor Silesian University of Technology, Poland
Department of Biomechatronics,
Faculty of Biomedical Engineering

Host

Divyaksh S. Chander

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ANYBODY TECHNOLOGY

Outline | Control Panel | AnyBody | Presentation | Resources | Q&A

Outlin

- Intr ystem

vents


Journal of Clinical Medicine

MDPI

Article

Progressive Loss of Muscle Strength: The Effects of Ageing and Sarcopenia on Muscle Function in Older Females

Katarzyna Nowakowska-Lipiec [1,*], Hanna Zadoń [1,2], Robert Michnik [1] and Agnieszka Nawrat-Szołtysik [3,4]

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Abstract: **Background/Objectives:** Sarcopenia is the progressive loss of muscle mass, strength, and/or function, leading to reduced physical performance, independence, and social participation. This study aimed to analyze the effects of age-related muscle strength loss and sarcopenia on muscle function during standing in older females. **Methods:** This study included experimental and modeling analyses using the AnyBody Modeling System in 20 older females. Based on DEXA results, participants were divided into older females without sarcopenia (OF) and with sarcopenia (OFS). Body posture while standing was assessed using the Zebris APCMS Pointer system. A model of muscular strength changes due to natural aging and progressive sarcopenia was developed based on literature data. The experimental results informed model studies in the AnyBody Modeling System, which incorporated changes in body posture with age and loss of muscle strength. **Results:** Total muscle activity during standing increases with age; however, this increase is significantly more pronounced in individuals with sarcopenia, especially after the age of 65. At 65 total muscle activity was 15% higher in the OFS model than in the OF model, while the difference was 44% at 80. After age 65, muscle fatigue increased considerably with progressive sarcopenia. At age 80, muscle fatigue while standing with sarcopenia can be more than three times higher than in those without sarcopenia. **Conclusions:** Aging leads to increased muscle activity while standing and sarcopenia further amplifies this effect, particularly in individuals over 65. Modeling results highlight the pronounced impact of sarcopenia on muscle fatigue, demonstrating its significant functional consequences in older females.

Keywords: ageing; sarcopenia; muscle strength; Anybody Modeling System; numerical simulations

check for updates

Academic Editors: Juan Mielgo-Ayuso and Natalia Busto

Received: 26 August 2025
Revised: 1 October 2025
Accepted: 9 October 2025
Published: 15 October 2025

Citation: Nowakowska-Lipiec, K.; Zadoń, H.; Michnik, R.; Nawrat-Szołtysik, A. Progressive Loss of Muscle Strength: The Effects of Ageing and Sarcopenia on Muscle Function in Older Females. J. Clin. Med. 2025, 14, 7276. https://doi.org/10.3390/jcm14207276

1. Introduction

Current demographic projections [1] show a steady increase older people (65+) within populations of most societies, with nu 1 billion by 2030 and 1.6 billion by 2050, comprising almost 2.5 by the end of the 21st century [1]. One of the principal cha is the global prevalence of lifestyle diseases often ass Aging is an exceptionally complex, irrev nomenon whose complexity depends on the

Presenter

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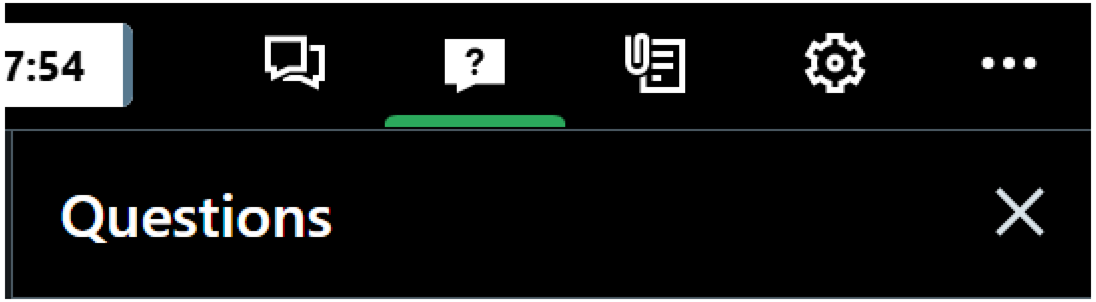
Submit questions and comments via the Questions panel.

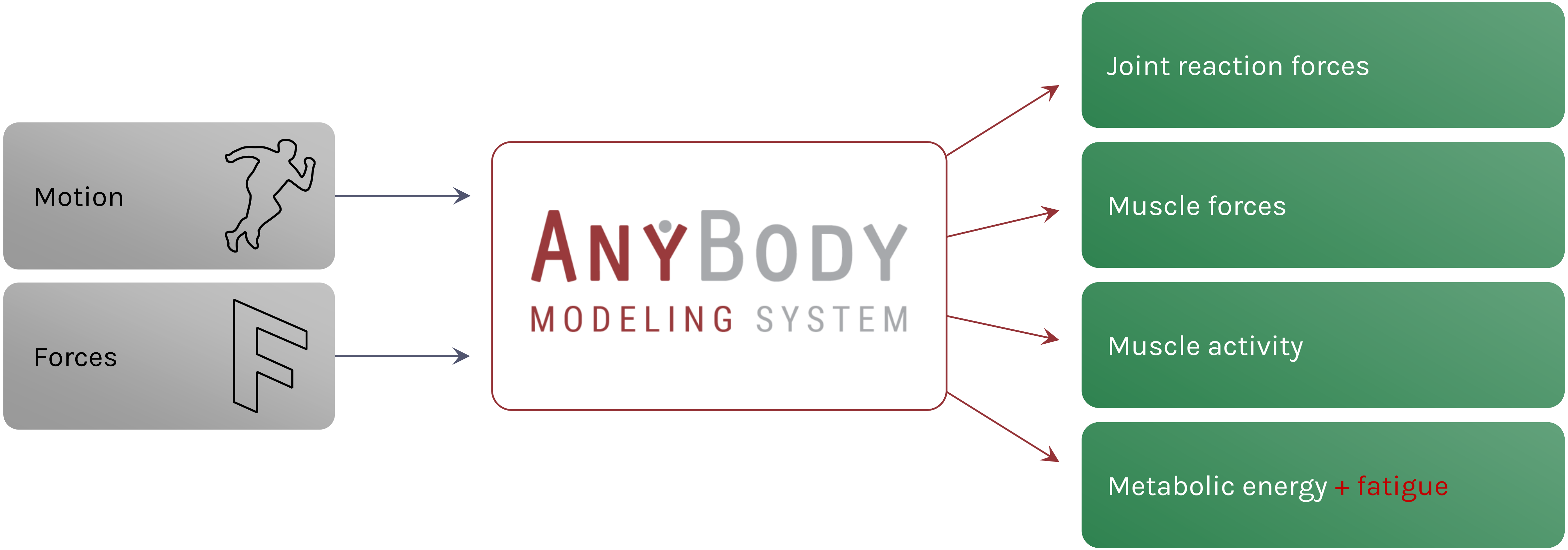
Questions will be addressed at the end of the presentation. If your question is not addressed, we will do so by email.



Musculoskeletal simulations

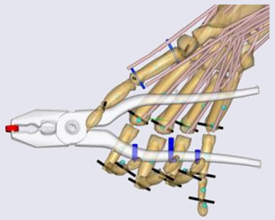
INPUT • Motion data

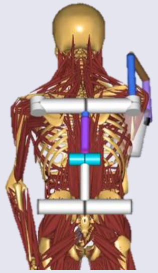
OUTPUT • Internal Body Loads



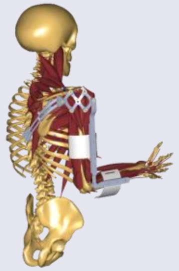
Motion analysis

Product design and optimization

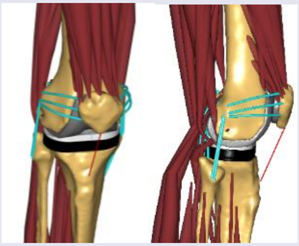




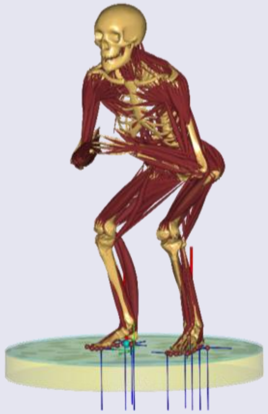
Ergonomics with/without exoskeletons



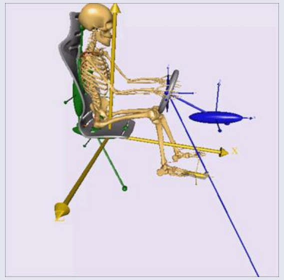
ANYBODY
MODELING SYSTEM



Orthopedics and Rehabilitation



Sports

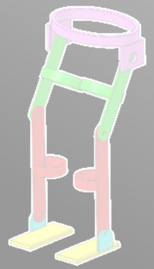


Automotive

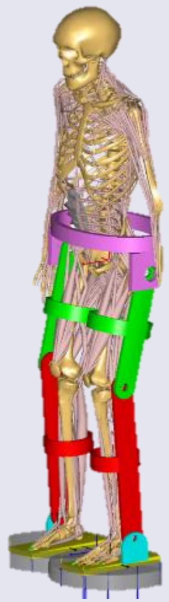
Workflow

Motions and forces

Body model

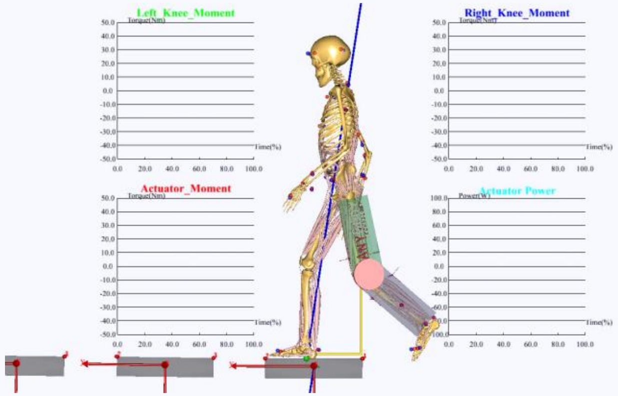


Environment model



Simulation

Inverse dynamics
Muscle recruitment



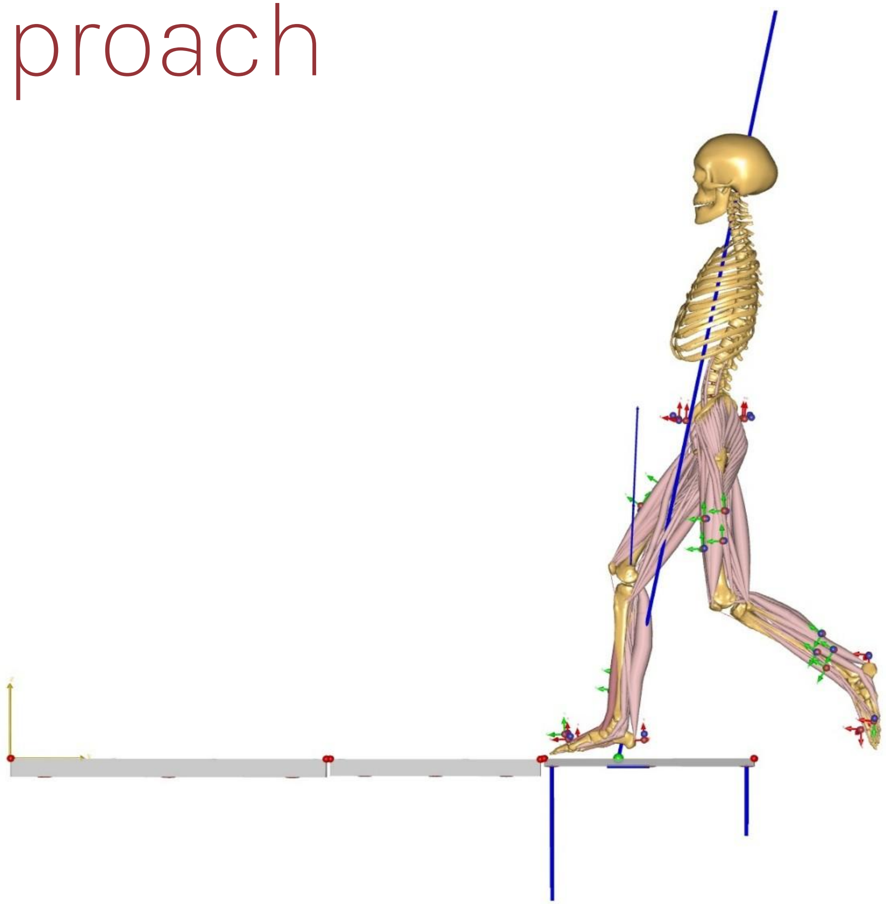
Internal body loads:

- Muscle forces
- Joint forces

Design Optimization

Post Processing
(e.g. Finite Element tools)

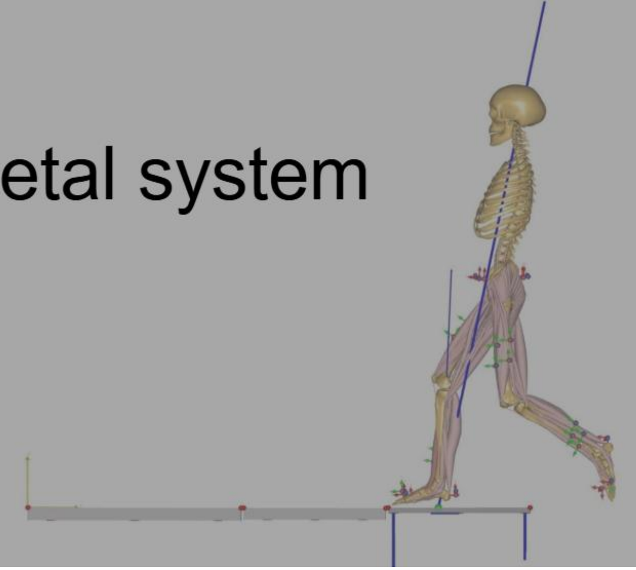
Age-related changes in the human musculoskeletal system: A modeling-based approach



Webcast: Age-related changes in the human musculoskeletal system
A modeling-based approach

Date: May 27, 2026
Time: 9AM (CEST) & 5PM (CEST)

READ MORE AND REGISTRATION



ANYBODY™ TECHNOLOGY

KATARZYNA NOWAKOWSKA-LIPIEC, PHD. ENG.

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RESEARCH UNIVERSITY EXCELLENCE INITIATIVE

Population Aging – A Global Challenge

Older adults represent an increasing proportion of the global population*

By 2030, the number of adults aged 65+ will exceed 1 billion**

By 2050, the older population will reach over 1.6 billion**

By the end of the 21st century, the global older population may approach 2.5 billion**

*United Nations, 2023; Dawson, A. & Dennison, E, 2016

** United Nations, 2023

Aging of the Musculoskeletal System

Sarcopenia

Loss of muscle mass beginning around the 3rd decade of life → up to 50% muscle mass reduction by the 8th decade

Dynapenia

Age-related decline in muscle strength → more pronounced in the lower limbs

Postural Compensations

Adaptive movement strategies → may increase joint loading and pain

Consequence

- Increased risk of falls
- Reduced independence
- Lower quality of life

Age-related musculoskeletal changes are inevitable, but their progression may be modified.

Why Biomechanical Modeling in Aging Research?

Experimental data

kinematics + GRF + anthropometry

↓

Musculoskeletal model

inverse dynamics + muscle recruitment optimization

↓

Internal biomechanics

joint loads + muscle forces + fatigue related indicators

From external movement data to internal biomechanical insight

Modeling-Based Analysis of Aging-Related Musculoskeletal Changes

Part I - Experimental-Driven Modeling Approach

Internal knee joint loading during walking

- Effects of age, sex, and physical activity
- Experimental gait analysis + musculoskeletal simulations
- Estimation of internal knee joint loading during gait

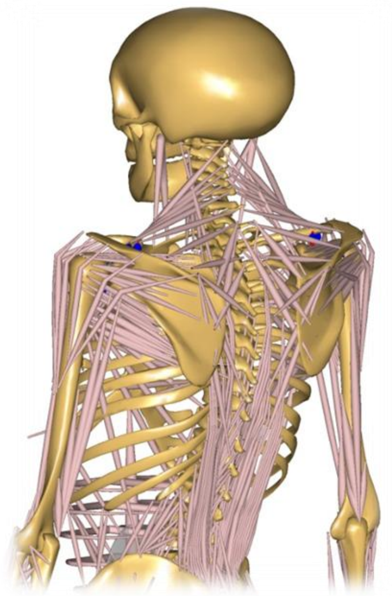
Part II – Simulation-Based Modeling Approach

From dynapenia to healthy aging

- Strength decline across aging
- Simulation-based analysis of upright standing
- Sex- and percentile-specific musculoskeletal models

Progressive Muscle Strength Loss with Age and Sarcopenia

- Strength decline across aging
- Simulation-based analysis of upright standing
- Musculoskeletal modeling with age-related postural changes



Aging-related biomechanical adaptations can be investigated using both experimental-driven and fully simulation-based musculoskeletal modeling approaches.

Age, sex and physical activity differences in the knee joint loadings during walking – a cross-sectional study

Hanna Zadoń, Katarzyna Nowakowska-Lipiec, Piotr Szaflik, Steriani Elavsky,
Jaroslaw Uchytil, Petr Kutáč, Jiří Skýpala, Daniel Jandačka

The aim of this cross-sectional cohort study was to assess differences in internal knee joint loading during walking according to age, sex, and physical activity level using musculoskeletal modeling.

KATEDRA STUDIÍ LIDSKÉHO POHYBU PEDAGOGICKÉ FAKULTY OU
OSTRAVSKÁ UNIVERZITA PEDAGOGICKÁ FAKULTA
LERCO
Faculty of Biomedical Engineering
Silesian University of Technology
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Materials & Methods

200
participants

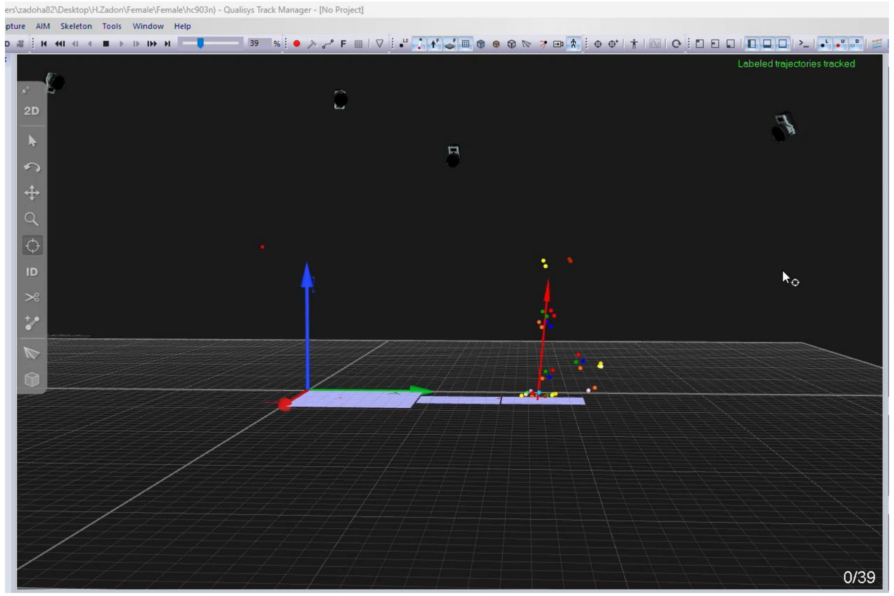
LERCO

Age, Sex And Physical Activity Differences In The Knee Joint Loadings During Walking – A Cross-Sectional Study

18-25 yrs	26-35 yrs	36-45 yrs	46-55 yrs	56-65 yrs
(40 participants)	(40 participants)	(40 participants)	(40 participants)	(40 participants)
20F: 10IN/10R	20F: 10IN/10R	20F: 10IN/10R	20F: 10IN/10R	20F: 10IN/10R
20M: 10IN/10R	20M: 10IN/10R	20M: 10IN/10R	20M: 10IN/10R	20M: 10IN/10R

F – Female, M – Male, IN – Inactive participants, R - Runners

The sample size was estimated using G*Power (α = 0.05, power = 0.80, ES = 0.25)



Human Motion Diagnostic Center,
Department of Human Movement Studies,
University of Ostrava

Faculty of Biomedical Engineering
Silesian University of Technology
RESEARCH UNIVERSITY
OSTRAVSKÁ UNIVERZITA
PEDAGOGICKÁ FAKULTA

Musculoskeletal model

Musculoskeletal Model

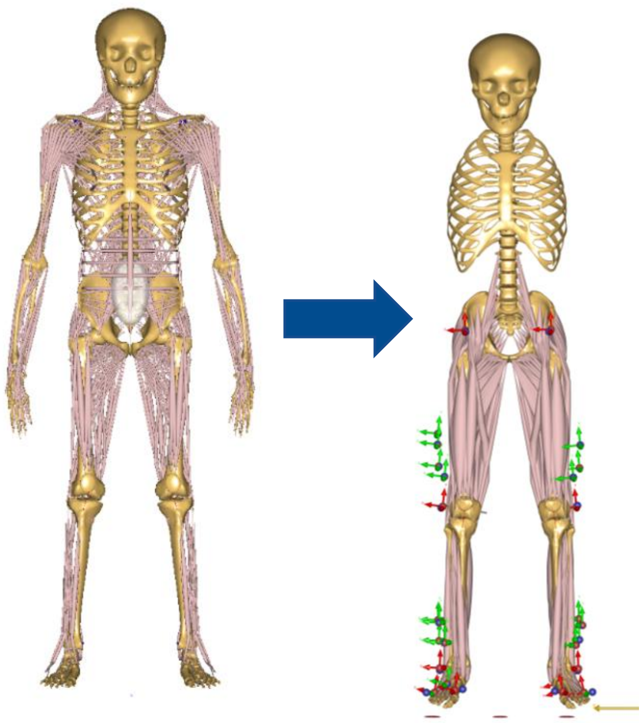
- **GaitFullModel** from the **AnyBody Managed Model Repository (AMMR)**
- **69 bones** connected by anatomically defined **kinematic joints**
- **>1000 muscle actuators** representing the muscular system
- **Upper limbs excluded** due to missing kinematic data

Input Data

- Motion capture (kinematic data)
- Ground reaction forces (GRF)
- Body height and body mass

Model Scaling

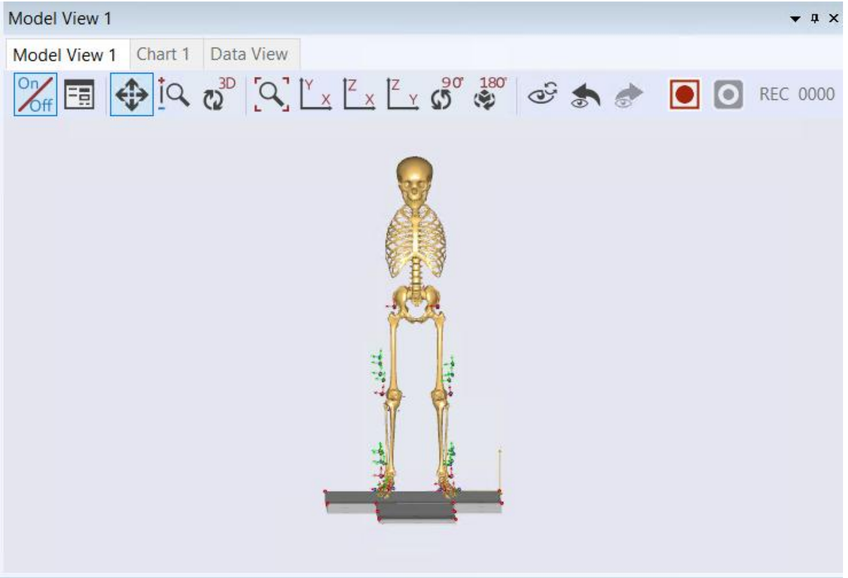
- Anthropometric scaling using **ScalingLengthMassFat**
- Segment dimensions and maximum muscle forces estimated from body mass, height, and body fat percentage



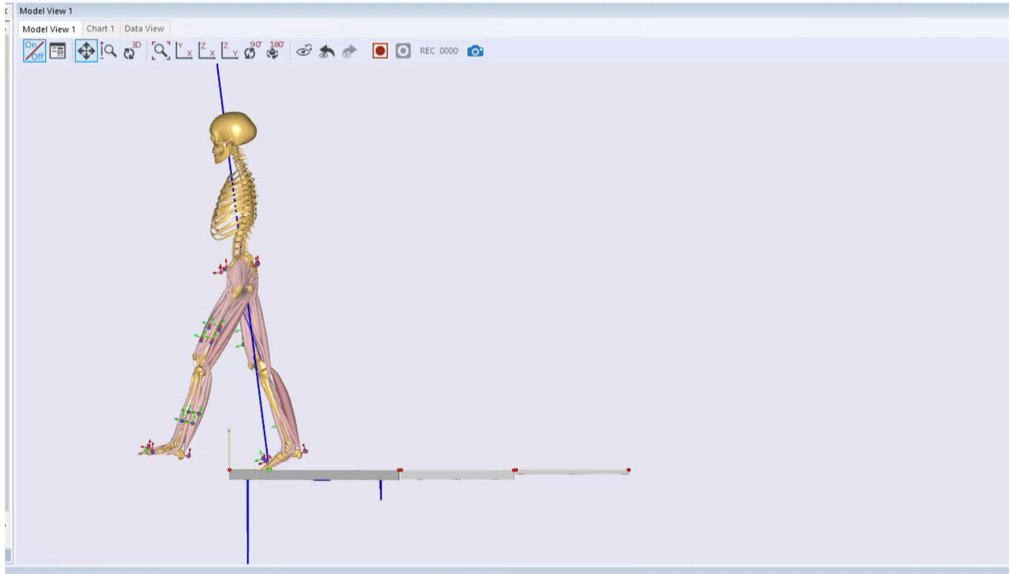
Materials & Methods

1 200
walking simulations

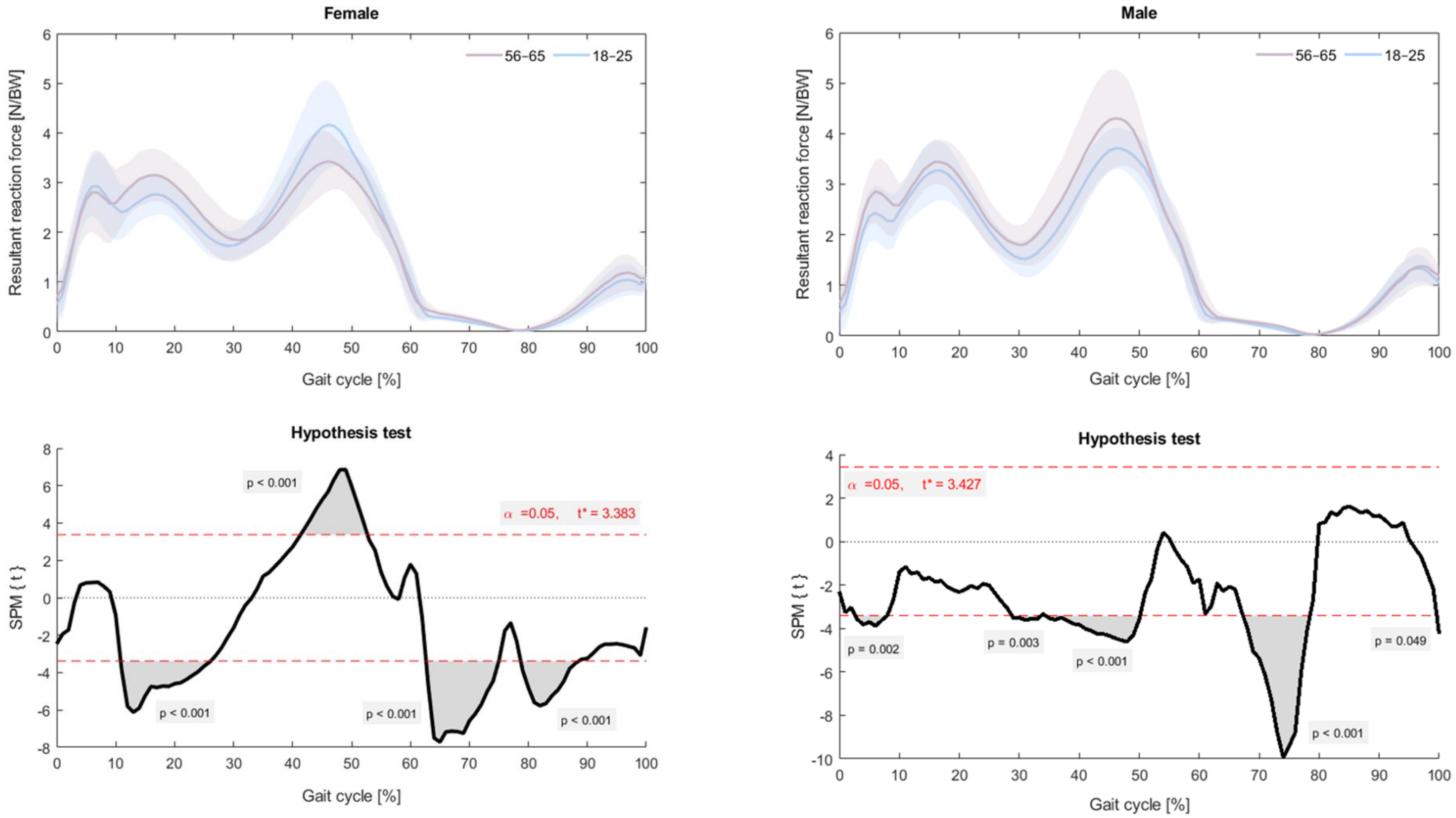
STATIC - STANDING POSITION
(200 simulations)



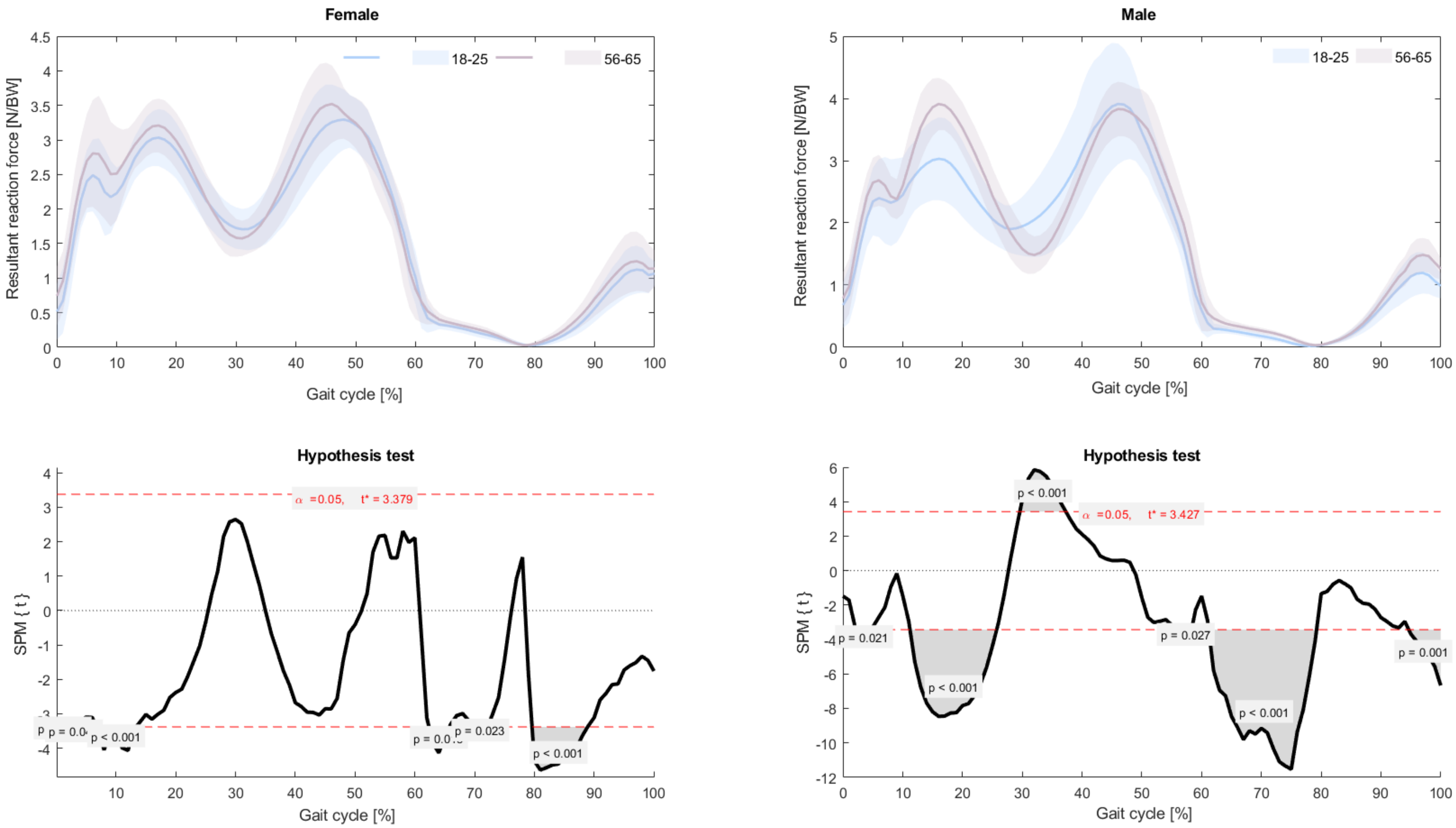
DYNAMIC – WALKING
200 persons x 6 gait cycles



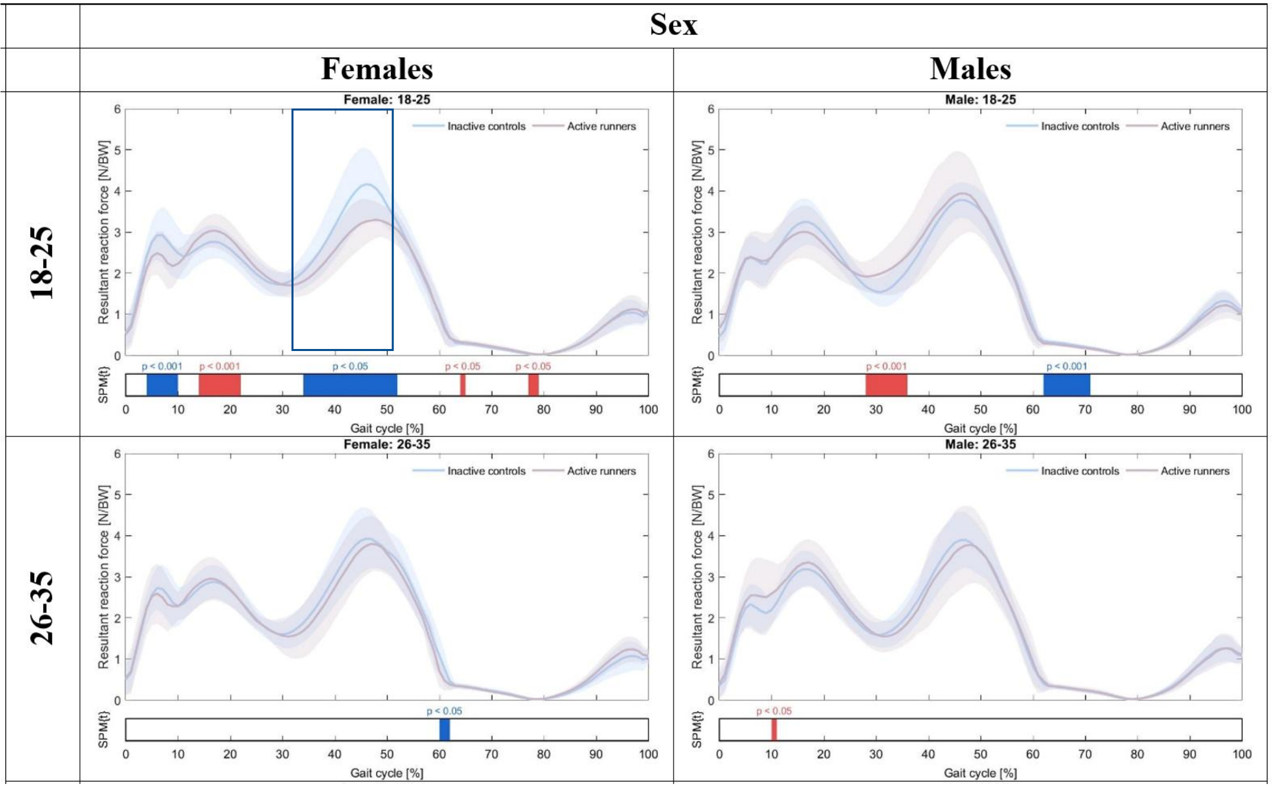
Results - Knee Joint Reaction Forces During Walking (Age) - Innactive Participants



Results - Knee Joint Reaction Forces During Walking (Age) - Runners



Results – Knee Joint Reaction Forces During Walking (Activity level)



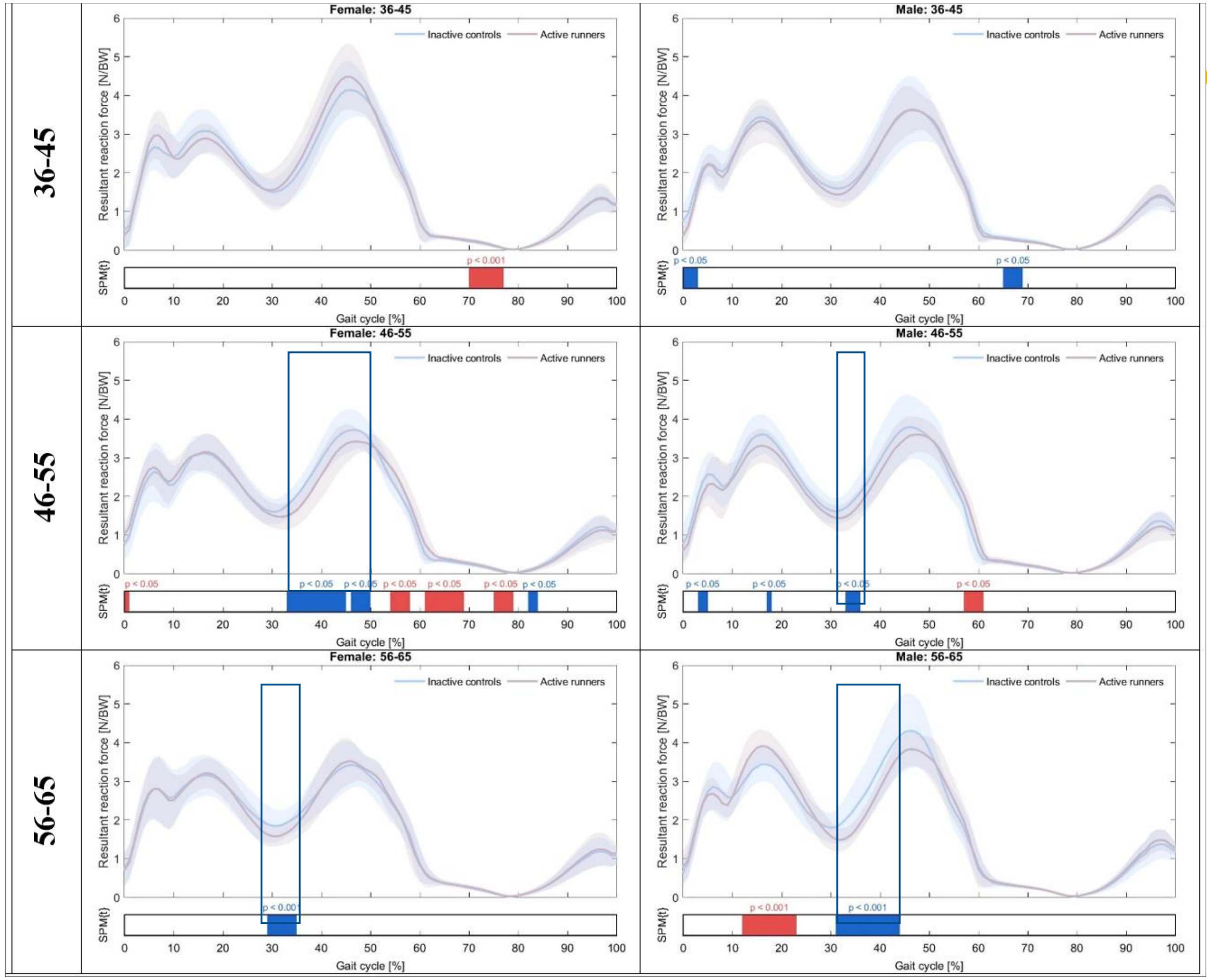


Fig. Resultant knee joint reaction forces during walking according to physical activity level (physically active vs. physically inactive individuals). Solid lines represent mean values, whereas shaded areas indicate standard deviations. The bar beneath the diagram indicates walking gait cycle intervals in which statistically significant differences were identified (SPM{t}, $p \leq 0.05$); blue indicates higher loading in physically inactive individuals, whereas red indicates higher loading in physically active individuals

Conlusions and directions for further analysis

Main Conclusions

- Age, sex and physical activity level are significantly associated with internal knee joint loading during walking.
- Older adults generally demonstrated lower knee joint loading relative to body weight
- Men generated higher internal knee joint forces than women.
- Regular physical activity was associated with reduced knee joint loading.
- Lifestyle and demographic factors may influence knee joint biomechanics and degenerative risk

Future Directions

- Analysis of individual knee joint reaction force components
- Evaluation of loading in other lower-limb joints
- Analysis of selected muscle forces and muscle activity patterns
- Expanded musculoskeletal loading analysis using AnyBody Modeling System

Directions for further analysis - Prospective study:
Association between aging and knee joint loading during gait

Katarzyna Nowakowska-Lipiec, Hanna Zadoń, Piotr Szaflik, Jiří Skýpala, Jaroslaw Uchytil, Petr Kutáč, Daniel Jandačka

60

participants

LERCO

Association between aging and knee joint loading during gait

1st wave – 2nd wave (after 5 years)

36-45 yrs	**46-55 yrs**	**56-65 yrs**
(20 participants)	(20 participants)	(20 participants)
10F: 5IN/5R	10F: 5IN/5R	10F: 5IN/5R
10M: 5IN/5R	10M: 5IN/5R	10M: 5IN/5R

F – Female, M – Male, IN – Inactive participants, R - Runners

The sample size was estimated using G*Power (α = 0.05, power = 0.80, ES = 0.25)

Katedra studií lidského pohybu, Pedagogická fakulta OU
Ostravská Univerzita, Pedagogická fakulta
Faculty of Biomedical Engineering
Silesian University of Technology
Research University, Excellence Initiative

FROM DYNAPENIA TO HEALTHY AGING: A BIOMECHANICAL MODELING-BASED ANALYSIS OF MUSCLE ACTIVITY AND FATIGUE

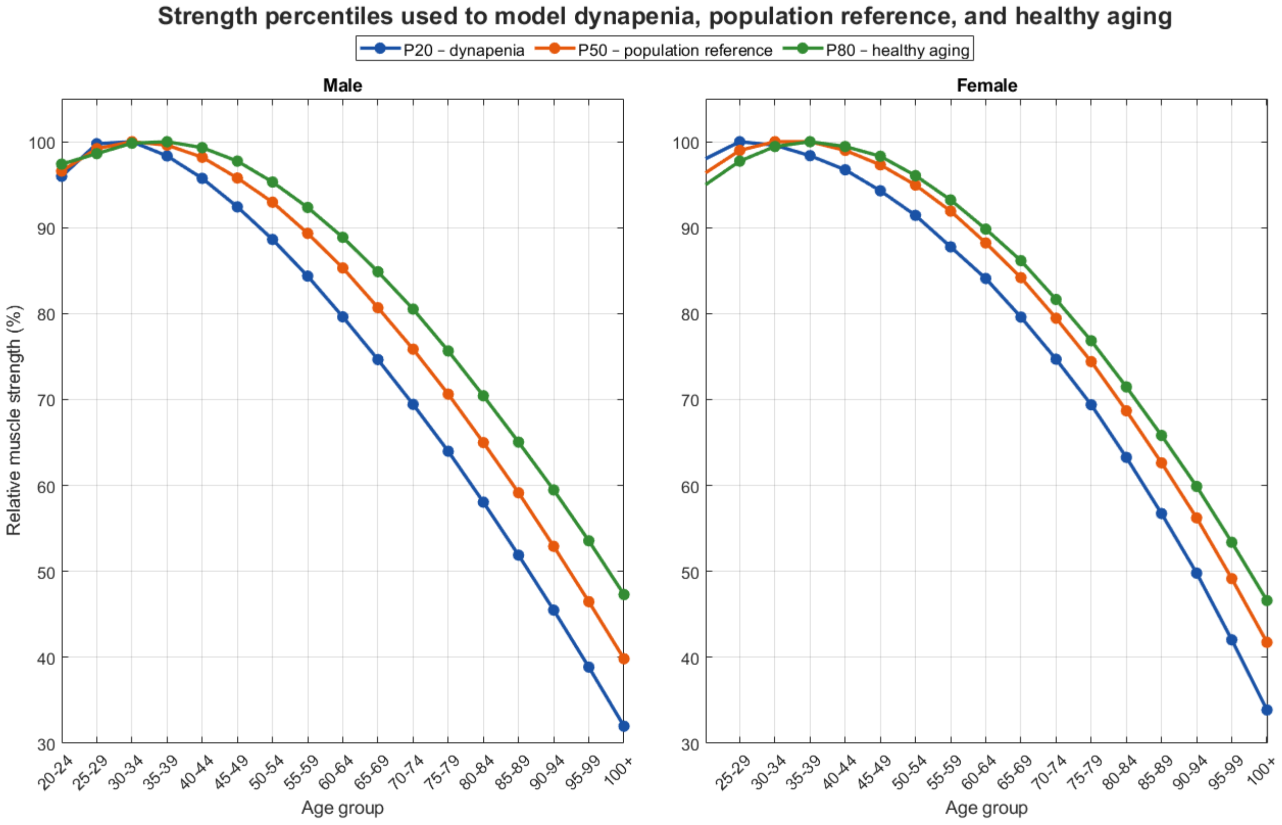
Katarzyna Nowakowska-Lipiec

The aim of this study was to evaluate, using mathematical musculoskeletal modelling, how age-related declines in muscle strength affect total muscle activity and muscle fatigue during upright standing across the 20th, 50th and 80th strength percentiles in males and females.

Faculty of Biomedical Engineering
Silesian University of Technology
RESEARCH UNIVERSITY EXCELLENCE INITIATIVE

Methods: Modeling Procedure

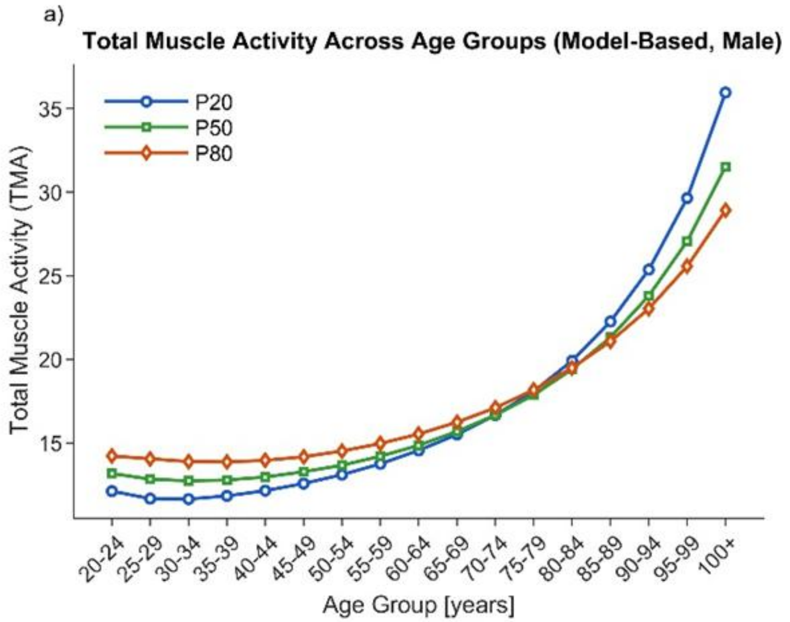
- Simulations performed in the **AnyBody Modeling System** Whole-body **Standing Model** with predicted GRF
- Muscle strength scaled using normative handgrip data
- Age- and sex-specific models: **20–24 to 100+ yrs**
- Strength percentiles: **P20 dynapenia, P50 reference, P80 healthy aging**
- Outcomes: **Total Muscle Activity** and **model-based muscle fatigue**

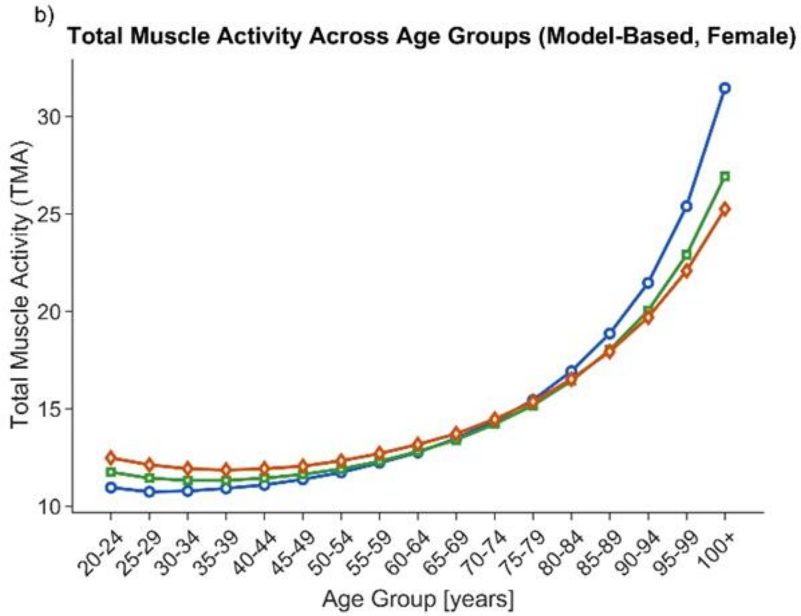


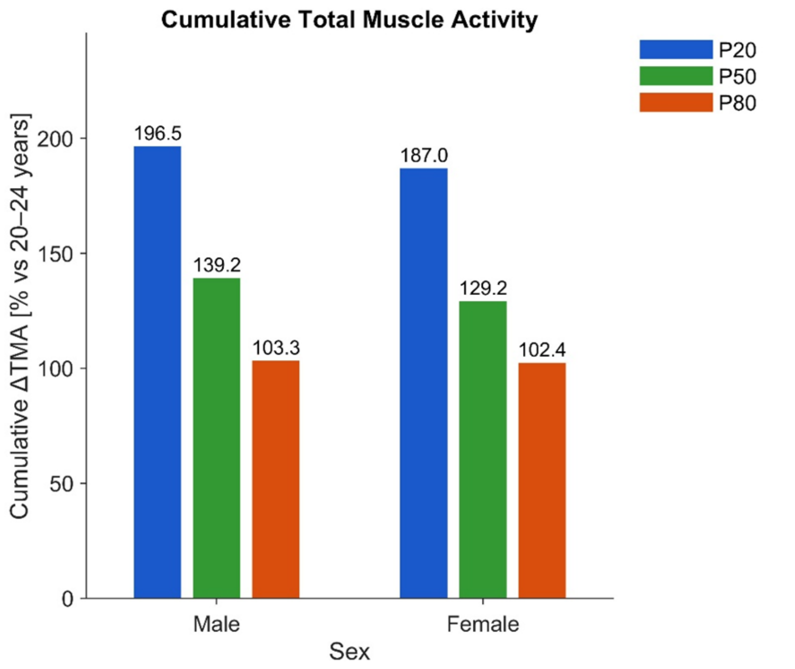
Strength scaling:
Tomkinson et al.* handgrip strength norms
2.4 million adults, 20–100+ yrs

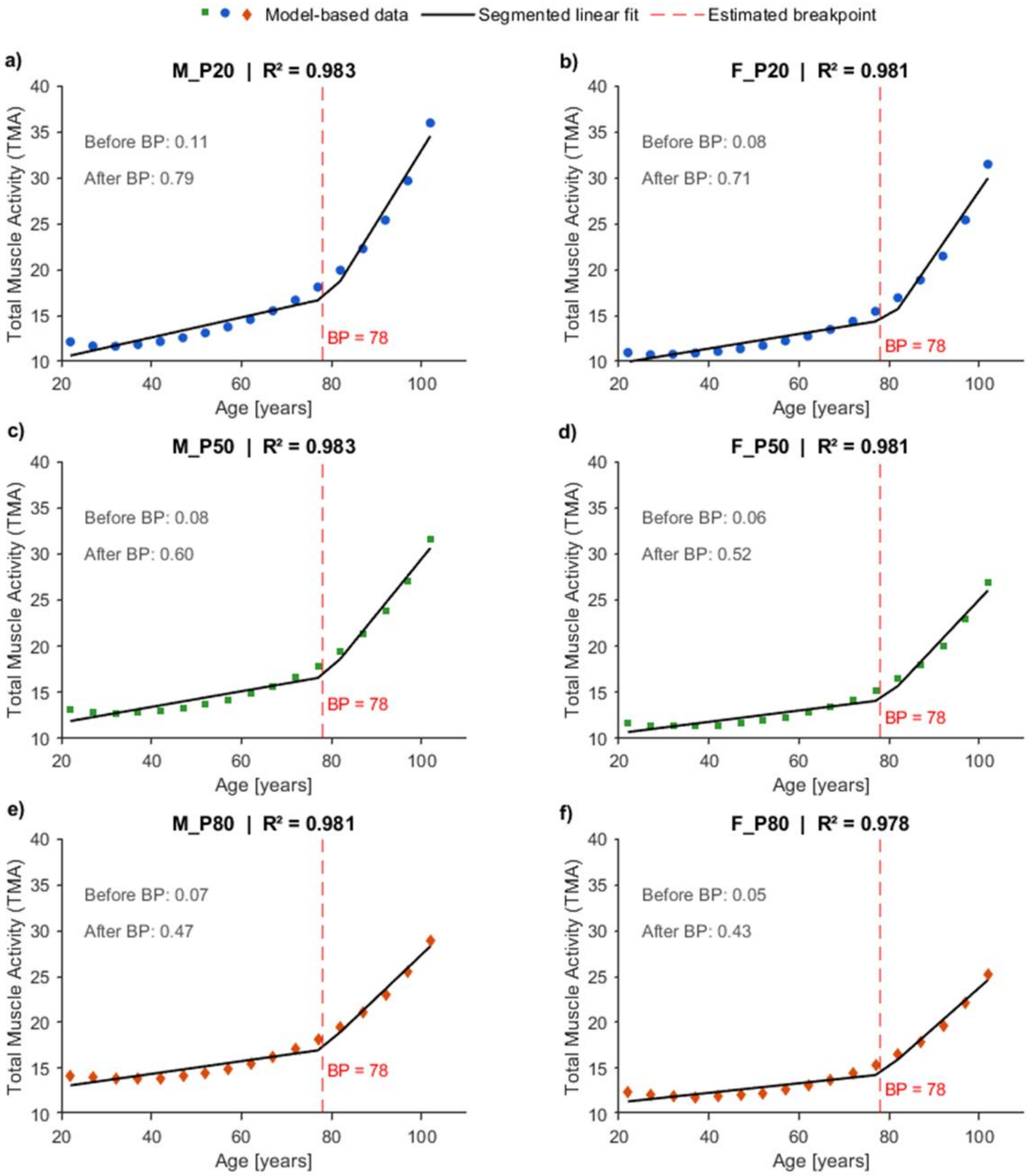
*Tomkinson GR, Lang JJ, Rubín L, et al. International norms for adult handgrip strength: A systematic review of data on 2.4 million adults aged 20 to 100+ years from 69 countries and regions. *J Sport Health Sci*. 2025;14:101014. doi:10.1016/j.jshs.2024.101014

Results: total muscle activity









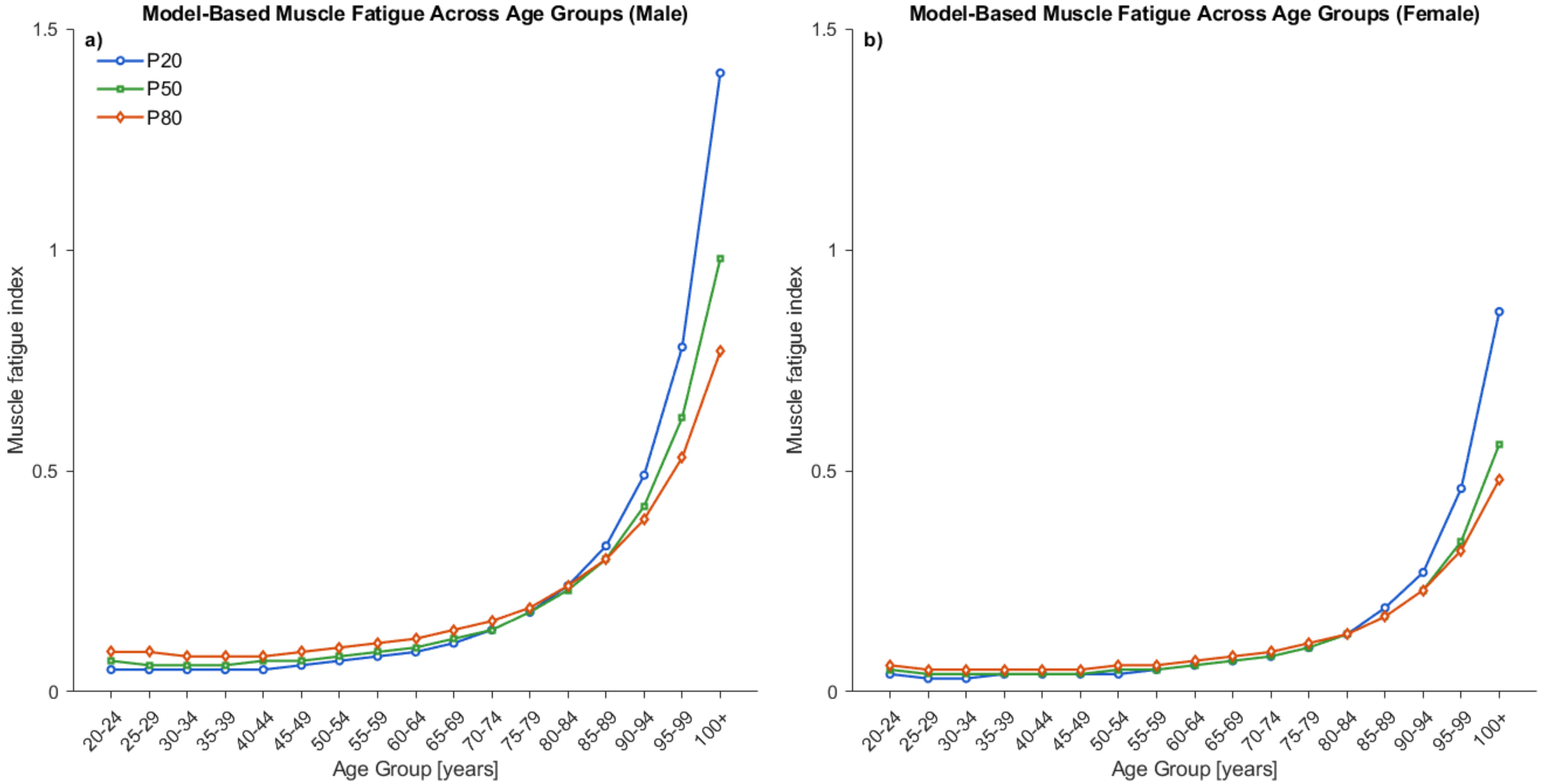
Results

Table Slopes of model-based total muscle activity (TMA) before and after the identified age-related breakpoint (78 years). Values represent mean slopes (ΔTMA per year) for men (M) and women (F) at the 20th, 50th, and 80th percentiles. Data are presented with 95% bootstrap confidence intervals.

Group	Slope before 78 yrs (ΔTMA/year, 95% CI)	Slope after 78 yrs (ΔTMA/year, 95% CI)	Fold increase
M_P20	0.109 (0.078–0.138)	0.789 (0.678–0.899)	×7.2
F_P20	0.080 (0.053–0.106)	0.711 (0.611–0.810)	×8.9
M_P50	0.085 (0.062–0.108)	0.600 (0.514–0.689)	×7.1
F_P50	0.061 (0.041–0.083)	0.517 (0.442–0.597)	×8.4
M_P80	0.069 (0.049–0.089)	0.467 (0.393–0.542)	×6.8
F_P80	0.052 (0.034–0.072)	0.432 (0.361–0.503)	×8.3

Legend: M – men; F – women; P20, P50, P80 – 20th, 50th, and 80th percentiles of maximal handgrip strength; TMA – total muscle activity; CI – confidence interval.

Results: model-based muscle fatigue



Modeled fatigue accelerates after ~60 yrs, especially in the P20 dynapenic profile

Figure. Model-based muscle fatigue across age groups for males (a) and females (b) at the 20th, 50th, and 80th strength percentiles (P20, P50, P80). Muscle fatigue was expressed as the optimization-based fatigue index derived from the AnyBody Modeling System simulations.

Conlusions

Main Conclusions

- Total muscle activity increased nonlinearly with age
- A marked acceleration occurred after approximately 60 yrs
- The highest muscular demands were observed in P20
- Muscle fatigue increased sharply in late life
- Reduced strength capacity amplifies the effort required for upright standing
- Modeling reveals internal biomechanical consequences of dynapenia

Dynapenia substantially increases the modeled muscular cost of maintaining upright posture, especially in late life.

PROGRESSIVE LOSS OF MUSCLE STRENGTH: THE EFFECT OF AGEING AND SARCOPENIA ON MUSCLE FUNCTION IN OLDER FEMALE

Katarzyna Nowakowska-Lipiec, Hanna Zadoń, Robert Michnik, Agnieszka Nawrat-Szołtysik

The aim of the study was to analyze the effects of age-related muscle strength loss and sarcopenia on muscle function during standing in older females.

Citation: Nowakowska-Lipiec, K.; Zadoń, H.; Michnik, R.; Nawrat-Szołtysik, A. Progressive Loss of Muscle Strength: The Effects of Ageing and Sarcopenia on Muscle Function in Older Females. *J. Clin. Med.* **2025**, *14*, 7276. https://doi.org/10.3390/jcm14207276

Research process

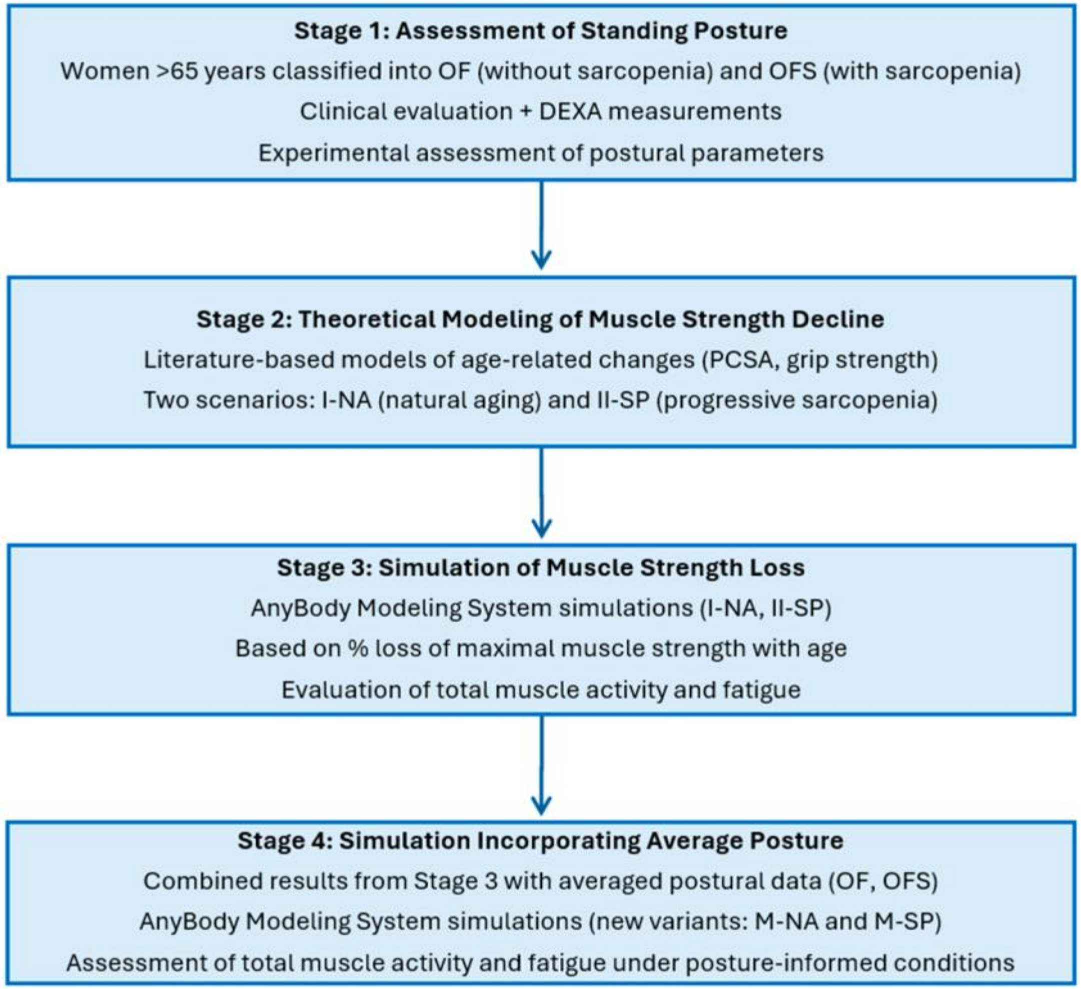


Figure 1. Four-stage research process: assessment of standing posture, theoretical modeling of muscle strength decline due to natural aging and progressive sarcopenia; musculoskeletal simulation of age-related muscle strength loss; and simulations incorporating body posture. Legend: OF—older females without sarcopenia; OFS—older females with sarcopenia; PCSA—physiological cross-sectional area of the muscle; I-NA—simulation variant accounting for the aging process defined by a model that assumes a percentage loss of maximum muscular strength with age due to the natural aging process; II-SP—simulation variant accounting for the aging process defined by a model assuming a percentage loss of maximal muscle strength with age in individuals with progressive sarcopenia; M-NA—model of the posture of OF and strength loss associated with natural aging processes; M-SP—model the posture of OFS and strength loss associated with progressive sarcopenia; Total muscle activity—the dimensionless sum of the activity of all muscle actions building the model; Total muscle fatigue—a dimensionless indicator from the optimization function, where higher values reflect greater fatigue.

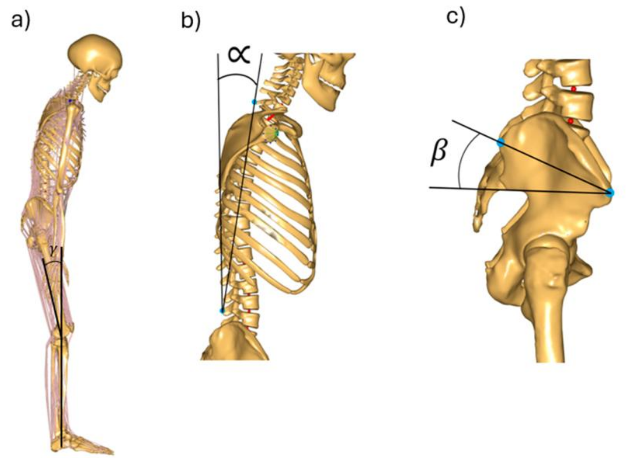
Study group and experimental assessment

20 women aged 65–88 years

- Mean age: 77 ± 7 years
- Body height: 1.57 ± 0.06 m
- Body mass: 67.4 ± 12.3 kg
- BMI: 27.31 ± 5.02 kg/m^2

DEXA – Sarcopenia Assessment

- Sarcopenia diagnosed based on the ALM index
- ALM = appendicular lean mass / height^2
- Cut-off value for women: ALM < 5.78 kg/m^2
- Based on DEXA densitometry assessment
- Classification into:
  - OF – older women without sarcopenia
  - OFS – older women with sarcopenia



Body posture assessment

- Standing assessment using the Zebris APGMS Pointer system
- Evaluation of trunk and pelvic alignment in the sagittal plane
  - α – trunk inclination angle: C7–L3 relative to the vertical axis
  - β – pelvic tilt angle: ASIS–PSIS relative to the horizontal axis

MODELLING STUDIES

- Developed to simulate age-related decline in muscle strength associated with natural aging and sarcopenia- using handgrip data from literature
- Two variants of muscle strength decline were considered:

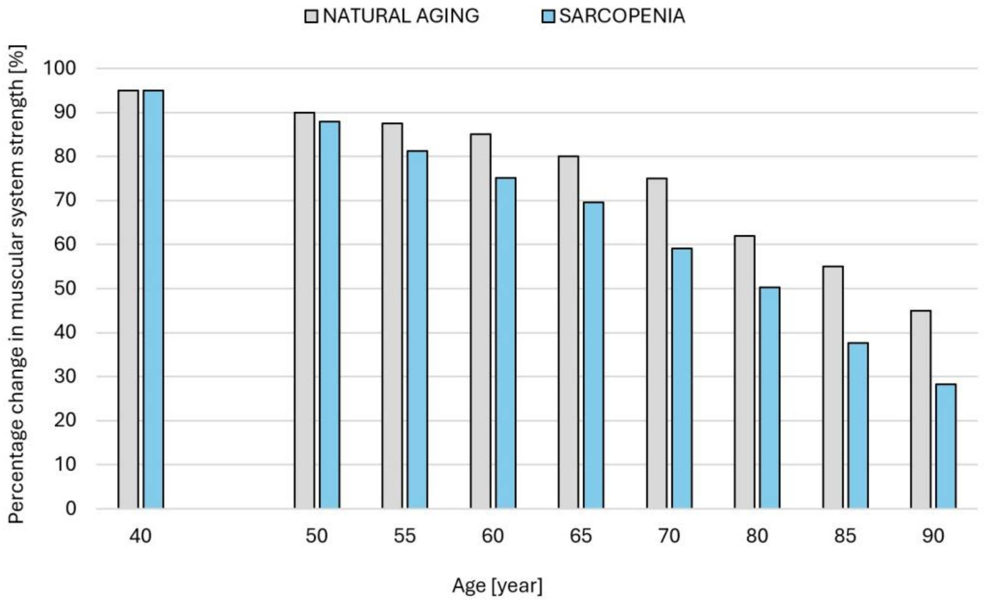
    - **NA – Natural aging -** Based on age-related changes in female handgrip strength reported by Dodds et al. (2016).

    - **SP – Sarcopenia** Based on literature data, the sarcopenia model assumed an accelerated decline in muscle strength from midlife, with substantial muscle loss by older age.

      Assumed strength decline:**
      - 40–50 yrs: 7.5%
      - 50–70 yrs: 7.5% every 5 yrs
      - 70–80 yrs: 15% every 5 yrs
      - 80–90 yrs: 25% every 5 yrs

      References: Metter et al. (1997), Faulkner et al. (2007), Walston (2012), Ko & Walston (2013).

- Muscle strength changes were modeled at 5-year intervals between 50 and 90 years of age.



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MODELLING STUDIES – ANYBODY MODELING SYSTEM

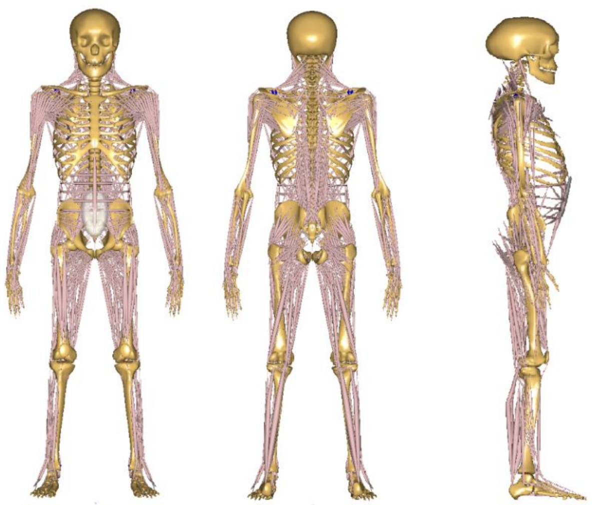
ANYBODY™ TECHNOLOGY

- Simulations performed in the **AnyBody Modeling System** Whole-body **Standing Model** with predicted GRF

- Three variants of muscle strength decline were modeled in older women:
    - **I-NA:** age-related loss of maximal muscle force due to **natural aging**
    - **II-SP:** accelerated age-related loss of maximal muscle force associated with **progressive sarcopenia**
    - **III-BP: age-related changes in body posture combined** with progressive loss of muscle strength associated with **natural aging and sarcopenia**

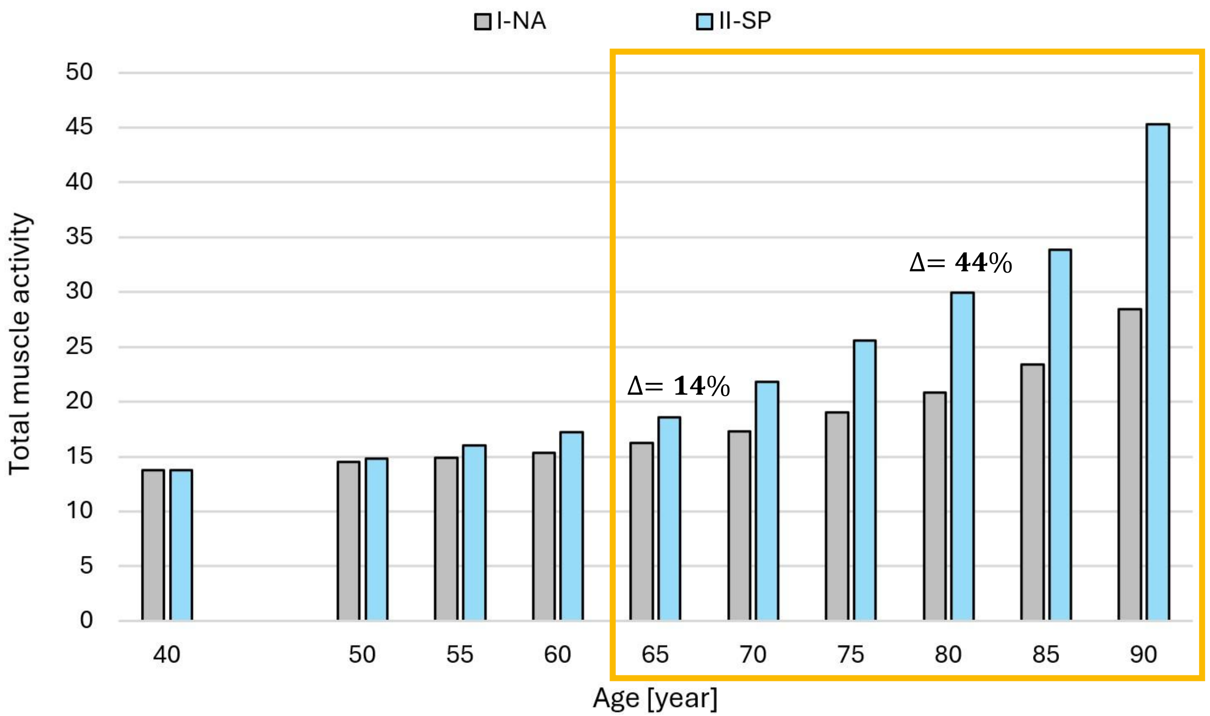
- Muscle strength changes were modeled at 5-year intervals between 50 and 90 years of age.

- Outcomes: **Total Muscle Activity, Muscle activity of selected postural muscles** and **model-based muscle fatigue**



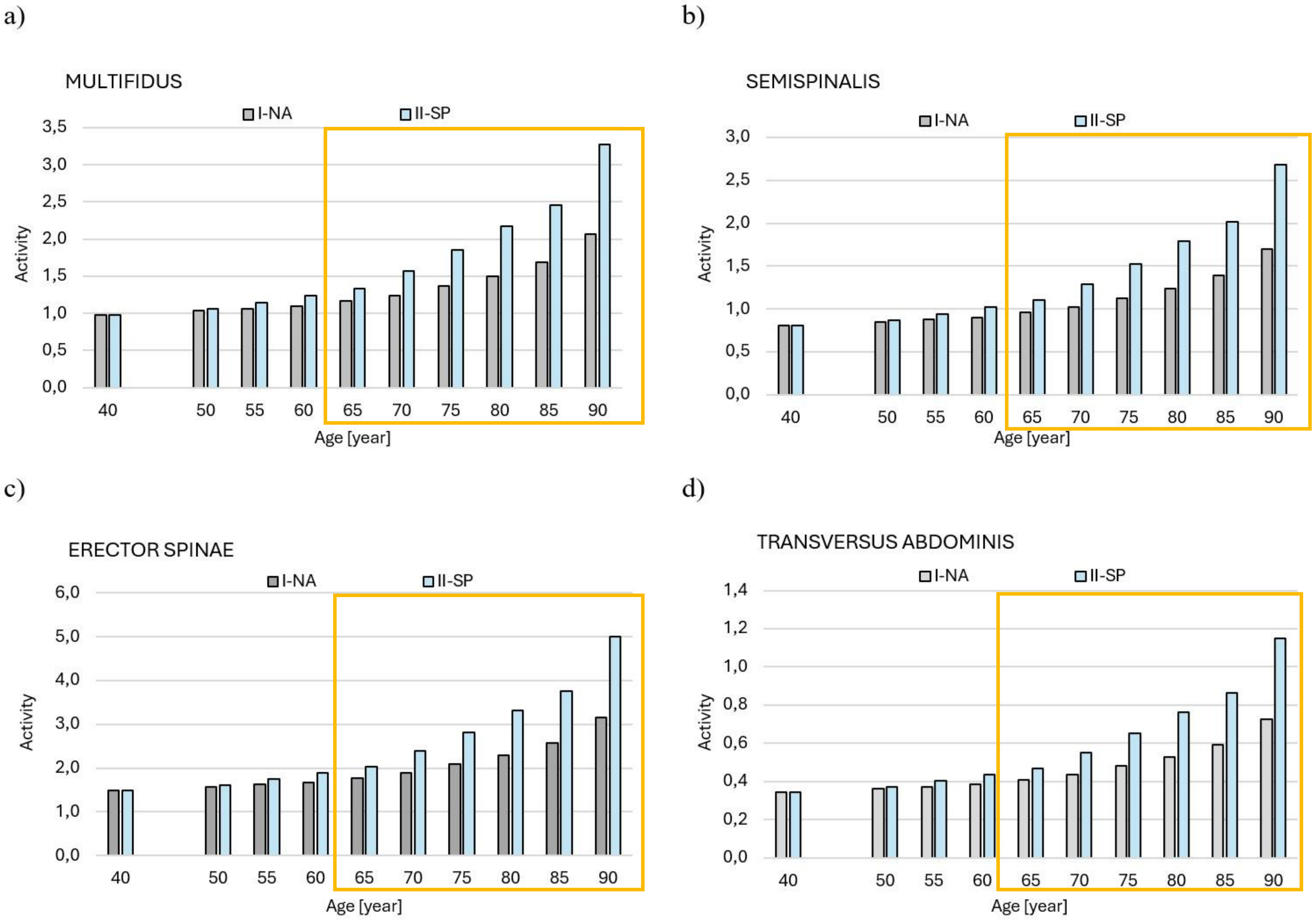
RESULTS

Total muscle activity of all muscles for the analyzed simulation variants I-NA and I-SP



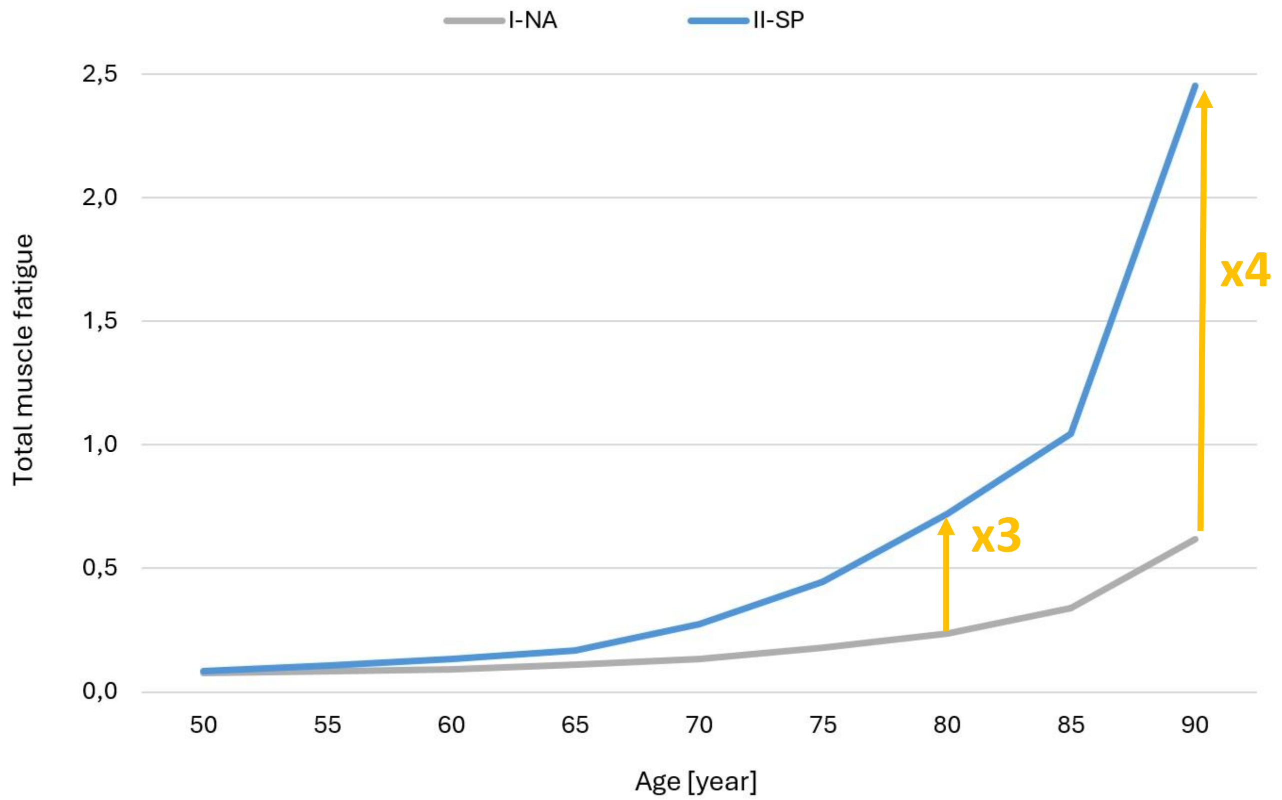
RESULTS

Muscle activity of selected muscles



RESULTS

Muscle fatigue for the analyzed simulation variants I-NA and I-SP



Age 60-65 yrs:

$\Delta_{I-NA\_5yrs} = 20\%$
$\Delta_{II-SP\_5yrs} = 27\%$

Age 65-70 yrs:

$\Delta_{I-NA\_5yrs} = 21\%$
$\Delta_{II-SP\_5yrs} = 62\%$

Age 70-75 and 75-80 yrs:

$\Delta_{I-NA\_5yrs} > 30\%$
$\Delta_{II-SP\_5yrs} > 60\%$

Age 80-85 yrs:

$\Delta_{I-NA\_5yrs} = 43\%$
$\Delta_{II-SP\_5yrs} = 45\%$

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RESULTS

Modeling results in older women considering body posture and muscle strength loss associated with natural aging and progressive sarcopenia

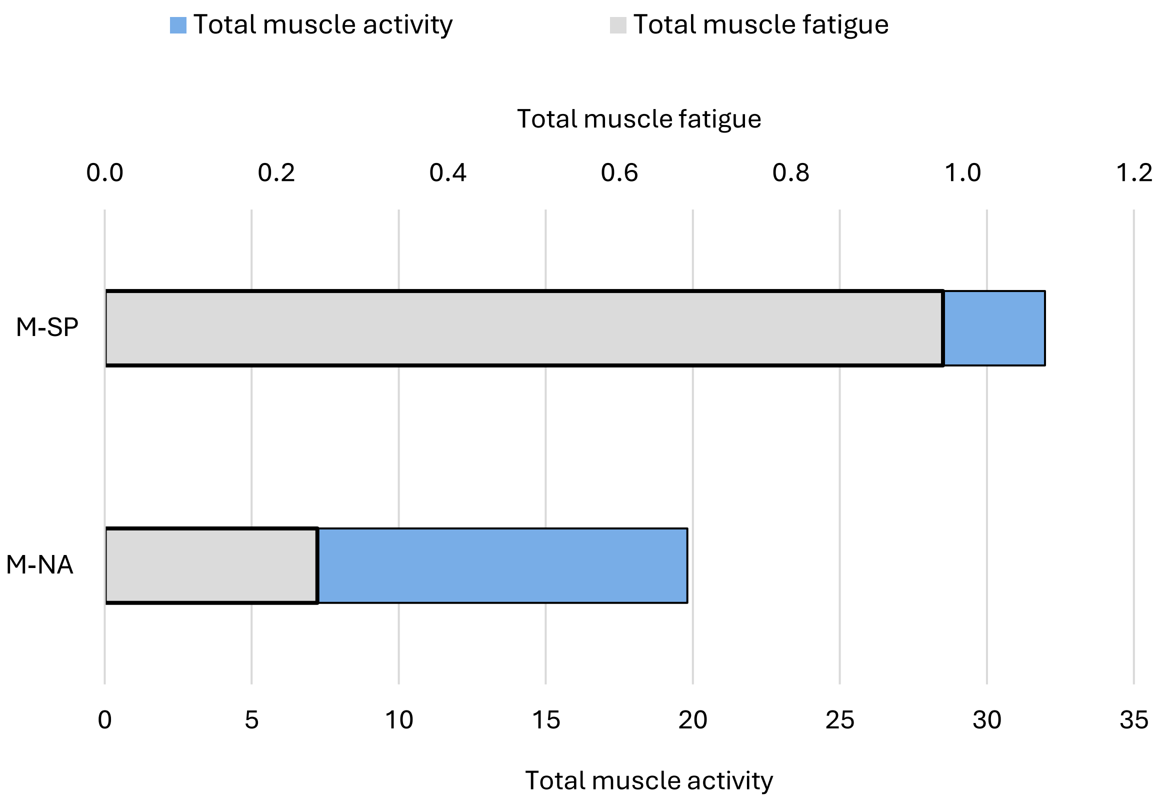


Table 2. Results of postural tests (trunk tilted and pelvis aligned in the sagittal plane).

Parameters	OF	OFS	*p*-Value (Cohen's d)
Trunk tilted in the sagittal plane (α) [°]	5.1° ± 3.8°	12.2° ± 6.2°	0.008 * (−1.38)
Pelvis aligned in the sagittal plane (β) [°]	9.7° ± 5.3°	14.3° ± 7.3°	0.126 (−0.72)

Legend: Values are presented as mean ± standard deviation. OF—older females without sarcopenia; OFS—older females with sarcopenia; * indicates statistical significance ($p < 0.05$).

Fig. Total muscle activity of all muscles and muscle fatigue in two models of older women considering body posture and muscle strength loss associated with natural aging (M-NA) and progressive sarcopenia (M-SP).

Conlusions

Main Conclusions

- Ageing increased total muscle activity during upright standing.
- Sarcopenia led to a faster increase in muscular demand, especially after the age of 65.
- At 65 years, total muscle activity was 15% higher in women with sarcopenia than in women undergoing natural aging. At 80 years, this difference increased to 44%.
- After 65 years, muscle fatigue increased markedly in women with progressive sarcopenia.
- At 80 years, standing-related muscle fatigue in women with sarcopenia may be more than three times higher than in women undergoing natural ageing only.

Future Perspectives in Modeling Musculoskeletal Aging

Strength personalization
Direct strength measurements

Muscle mass & body composition
Body composition- and morphology-informed scaling

Aging-specific muscle behavior
Force capacity, contraction properties, fatigue response

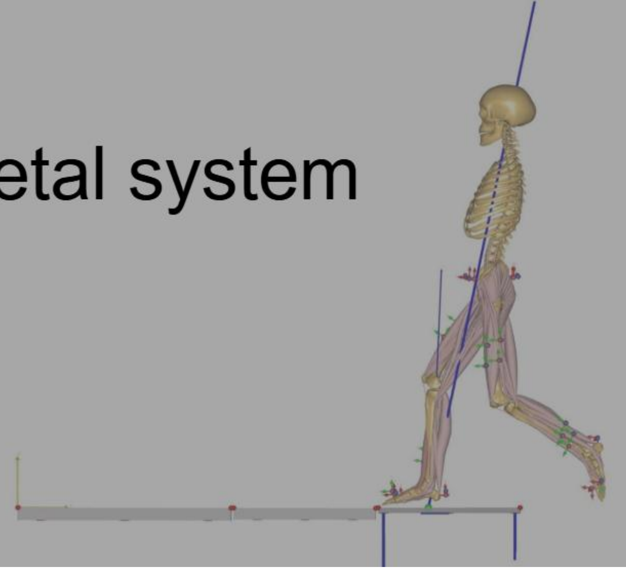
Personalized aging profiles
Healthy aging, dynapenia, sarcopenia

Te next step in aging research is to further personalize musculoskeletal models by integrating strength measurment, muscle mass, body-composition and functional phenotype data.

Webcast: Age-related changes in the human musculoskeletal system
A modeling-based approach

Date: May 27, 2026
Time: 9AM (CEST) & 5PM (CEST)

READ MORE AND REGISTRATION



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THANK YOU

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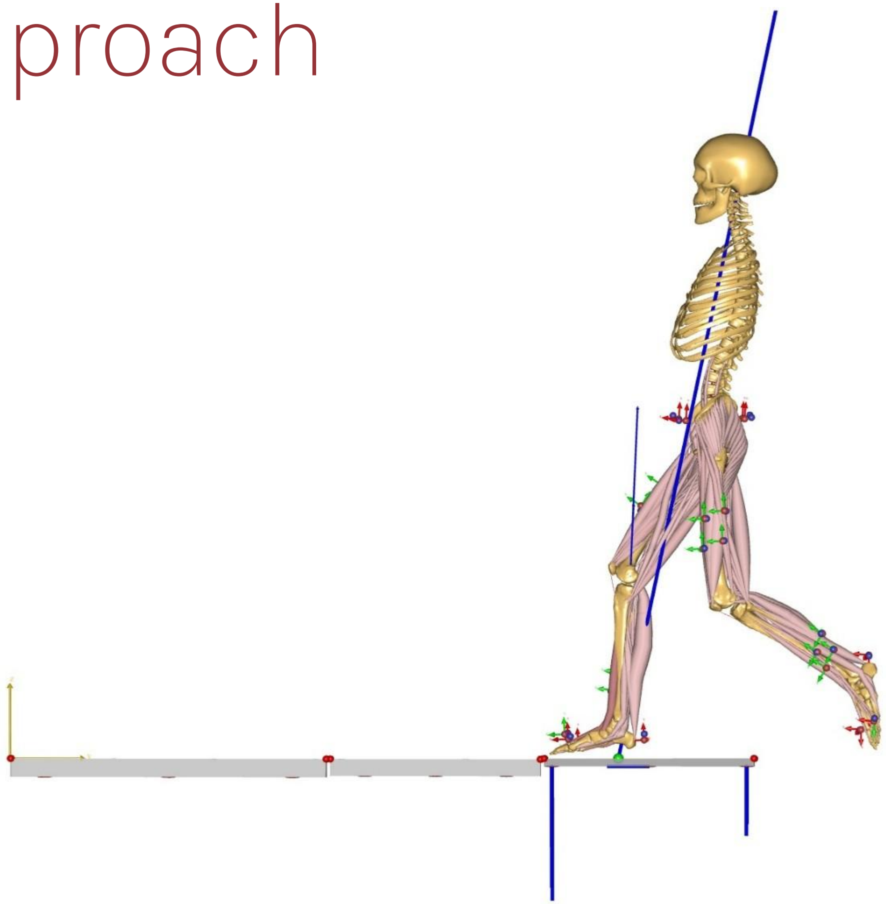
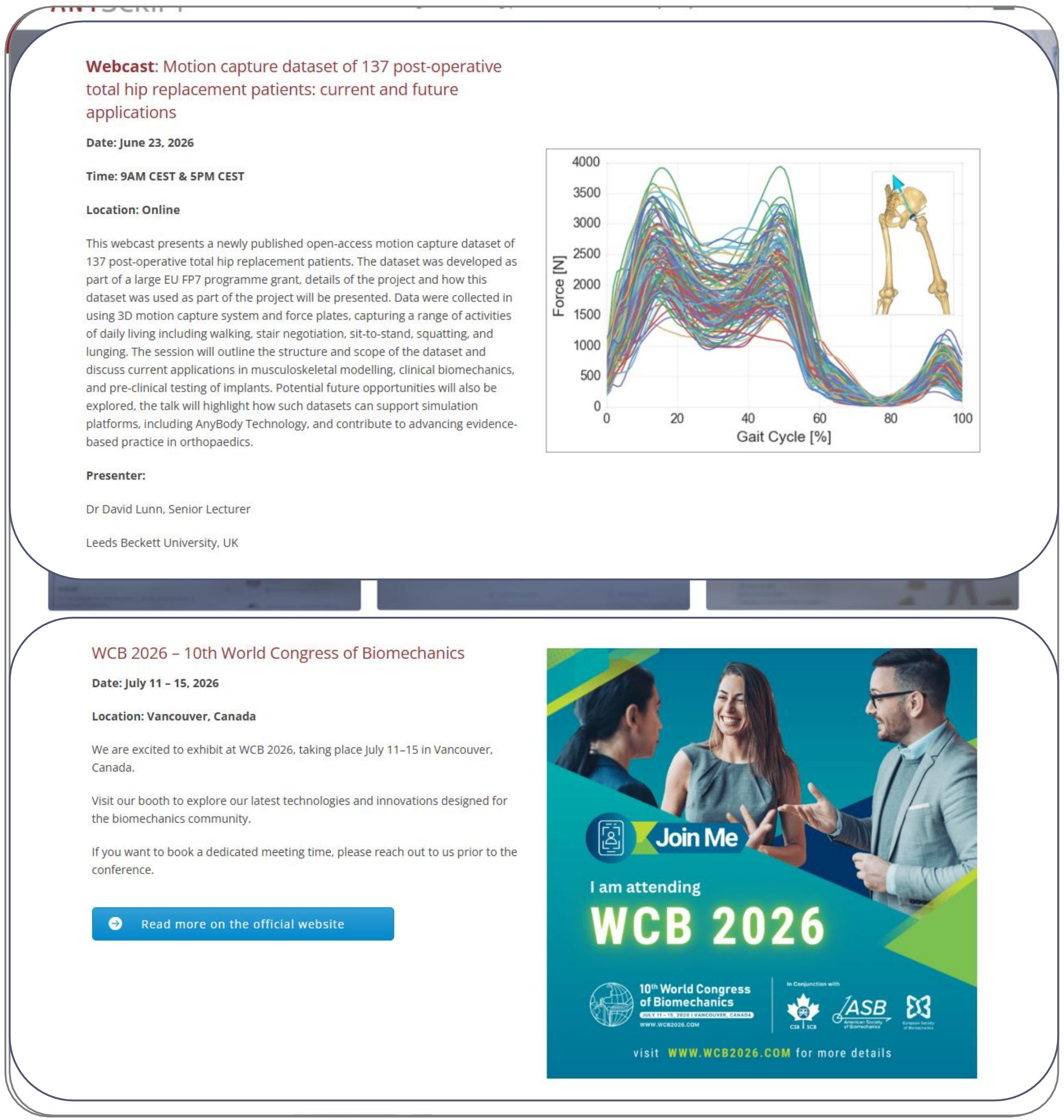
Age-related changes in the human musculoskeletal system: A modeling-based approach



Resources

- **www.anybodytech.com**
  - Events, Webcast library, Publication list, …
- **www.anyscript.org**
  - Wiki, Blog, Repositories, Forum
- **Events**
  - Webcast: MoCap dataset of total hip replacement patients
    - June 23, 2026; 09.00 am and 05.00 pm CEST
  - WCB 2026 (10th World Congress of Biomechanics)
    - July 11 – 15, 2026; Vancouver Canada



Webcast: Motion capture dataset of 137 post-operative total hip replacement patients: current and future applications

Date: June 23, 2026

Time: 9AM CEST & 5PM CEST

Location: Online

This webcast presents a newly published open-access motion capture dataset of 137 post-operative total hip replacement patients. The dataset was developed as part of a large EU FP7 programme grant, details of the project and how this dataset was used as part of the project will be presented. Data were collected in using 3D motion capture system and force plates, capturing a range of activities of daily living including walking, stair negotiation, sit-to-stand, squatting, and lunging. The session will outline the structure and scope of the dataset and discuss current applications in musculoskeletal modelling, clinical biomechanics, and pre-clinical testing of implants. Potential future opportunities will also be explored, the talk will highlight how such datasets can support simulation platforms, including AnyBody Technology, and contribute to advancing evidence-based practice in orthopaedics.

Presenter:

Dr David Lunn, Senior Lecturer

Leeds Beckett University, UK

WCB 2026 – 10th World Congress of Biomechanics

Date: July 11 – 15, 2026

Location: Vancouver, Canada

We are excited to exhibit at WCB 2026, taking place July 11–15 in Vancouver, Canada.

Visit our booth to explore our latest technologies and innovations designed for the biomechanics community.

If you want to book a dedicated meeting time, please reach out to us prior to the conference.

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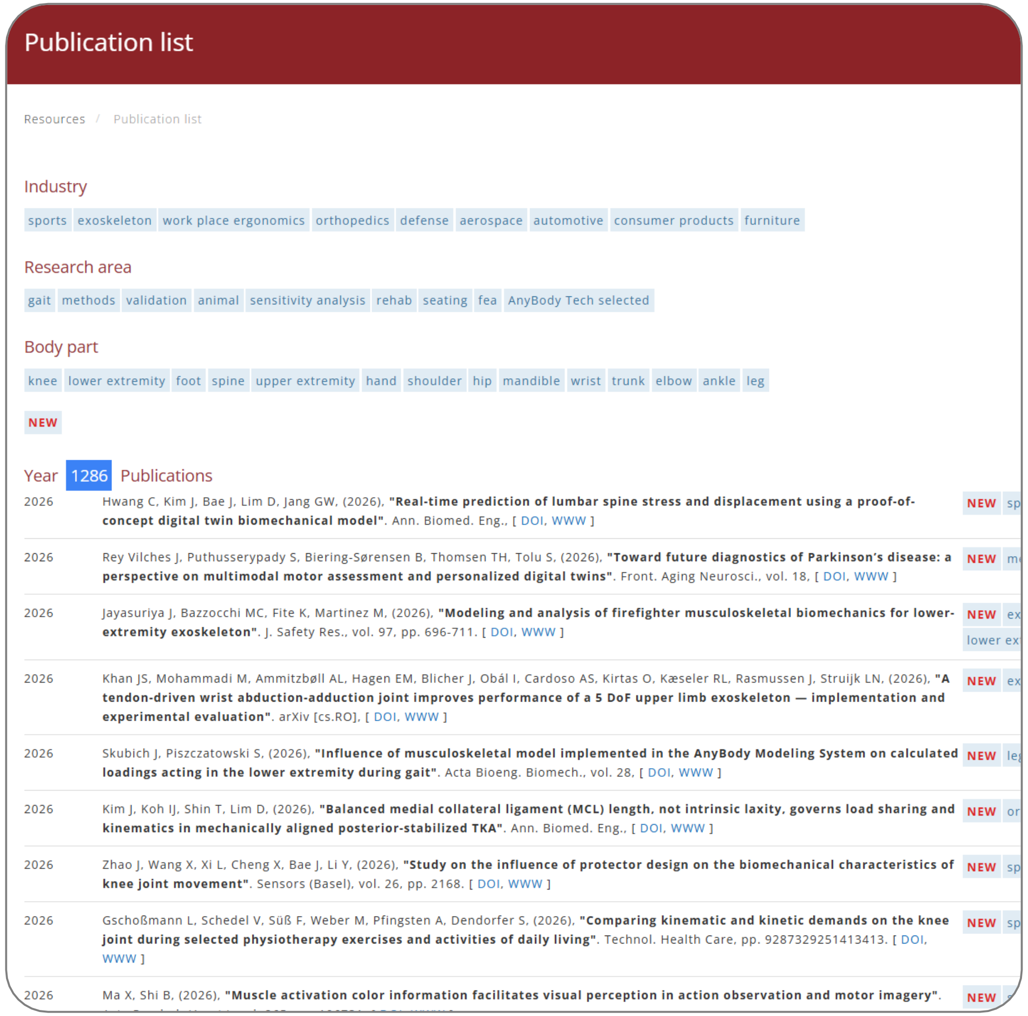
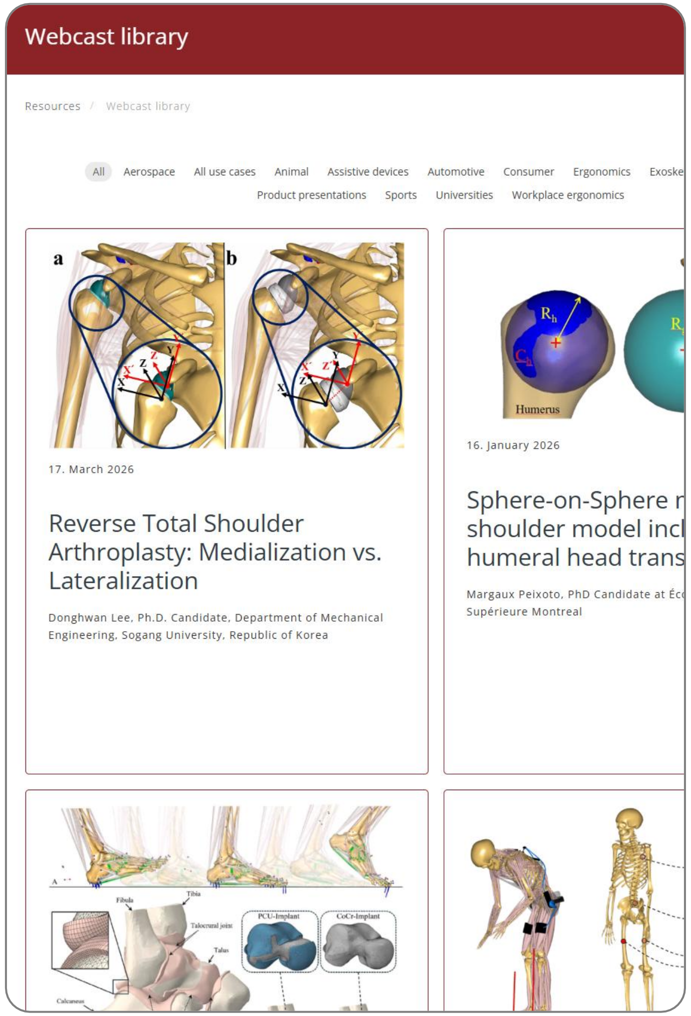


[Publications list](#)



[Webcasts list](#)

Questions

Meet us

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Trial version

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Presentation questions

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Thank you for your attention!