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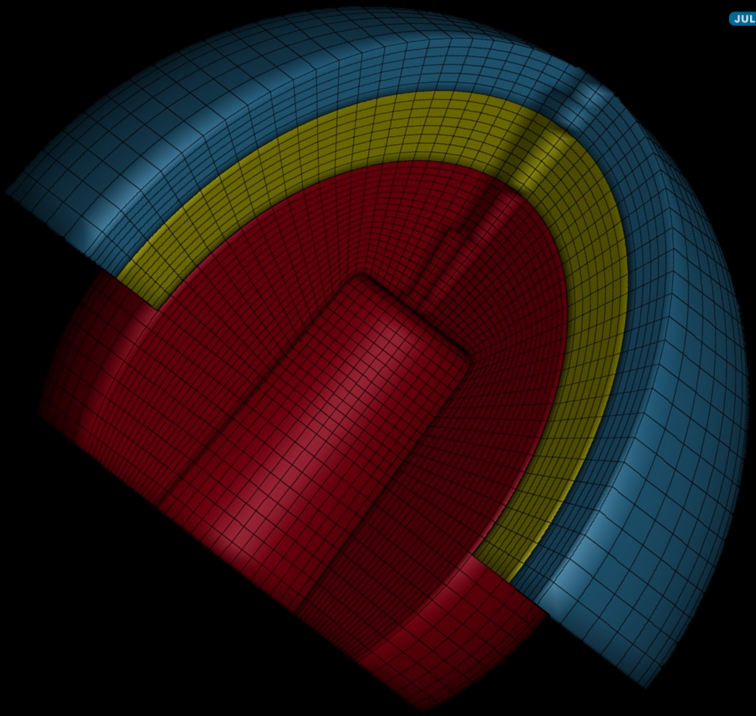
WEAR ANALYSIS OF TOTAL HIP ARTHROPLASTY

Under Subject-Specific Walking & Running
in a Young-Age, Low-BMI Group



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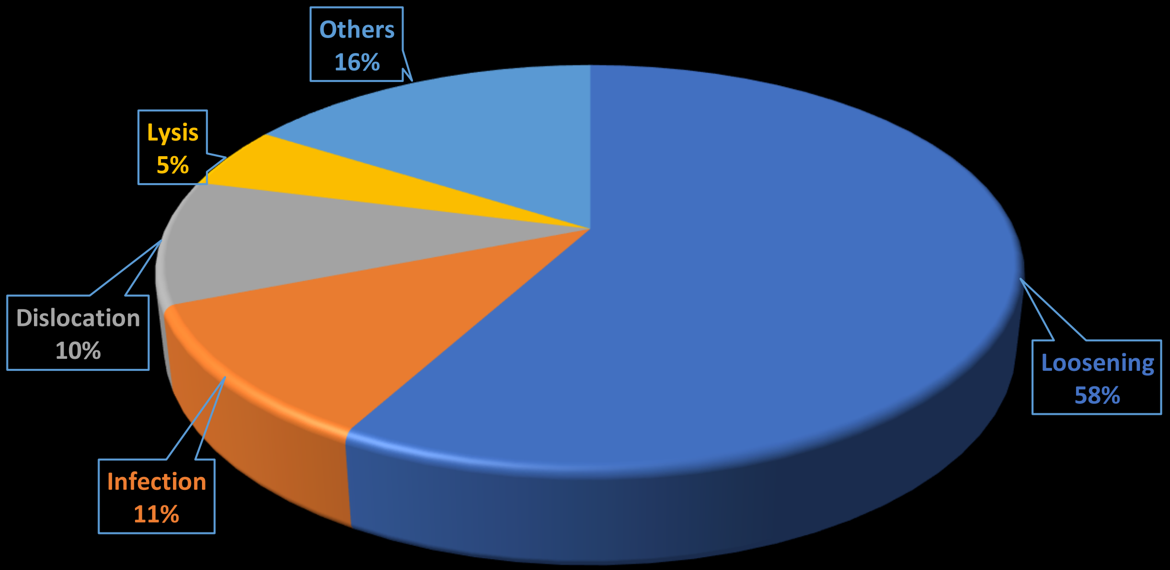
Rising Total Hip Replacement (THR) Demand [1]

- By 2030, 52% of primary THR in patients <65 yrs
- Strongest growth: 45–55 year age group

Implant's Failure [2]

- Polyethylene (XLPE)-based materials , loosening is the major implant failure [2]



Causes of failure of hip joint replacements

Wear and Wear Particles

- Excessive wear (threshold of 0.1mm/year) could trigger osteolysis [3]

[3] Bergvinsson H, et al. 2021

THE CLINICAL PROBLEM

Low-impact era

Normal daily activates, cycling, swimming encouraged after THR → minimal wear concern

Younger patients demand more

Running, basketball, tennis → now common expectation, not exception

The wear risk

Higher forces + larger ROM = accelerated XLPE wear → osteolysis → revision

The question asked by patients

- Is it safe for me to return activities including running?
- If it is safe, how much I can do without affecting my hip/knee implants?

Limited quantitative, subject-specific data on implant safety higher impact tasks (e.g., running)

Our study aims to help answer these questions with quantitative evidence based on wear analysis

MOTION CAPTURE

11 active patients with THR
6F / 5M, Age 55.9±9.8 yrs
BMI 22.8±2.8
≥12 months post-op

Musculoskeletal modelling

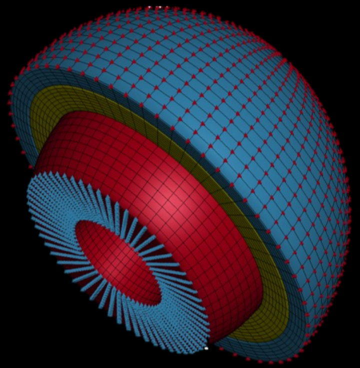
3D joint loads and motions estimation
(AnyBody)
Walking + Running

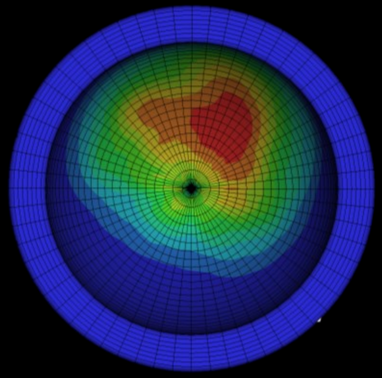
FE MODELLING

CoCr head / XLPE liner
LS-DYNA Explicit
Archard wear law
5 million cycles

WEAR OUTPUT

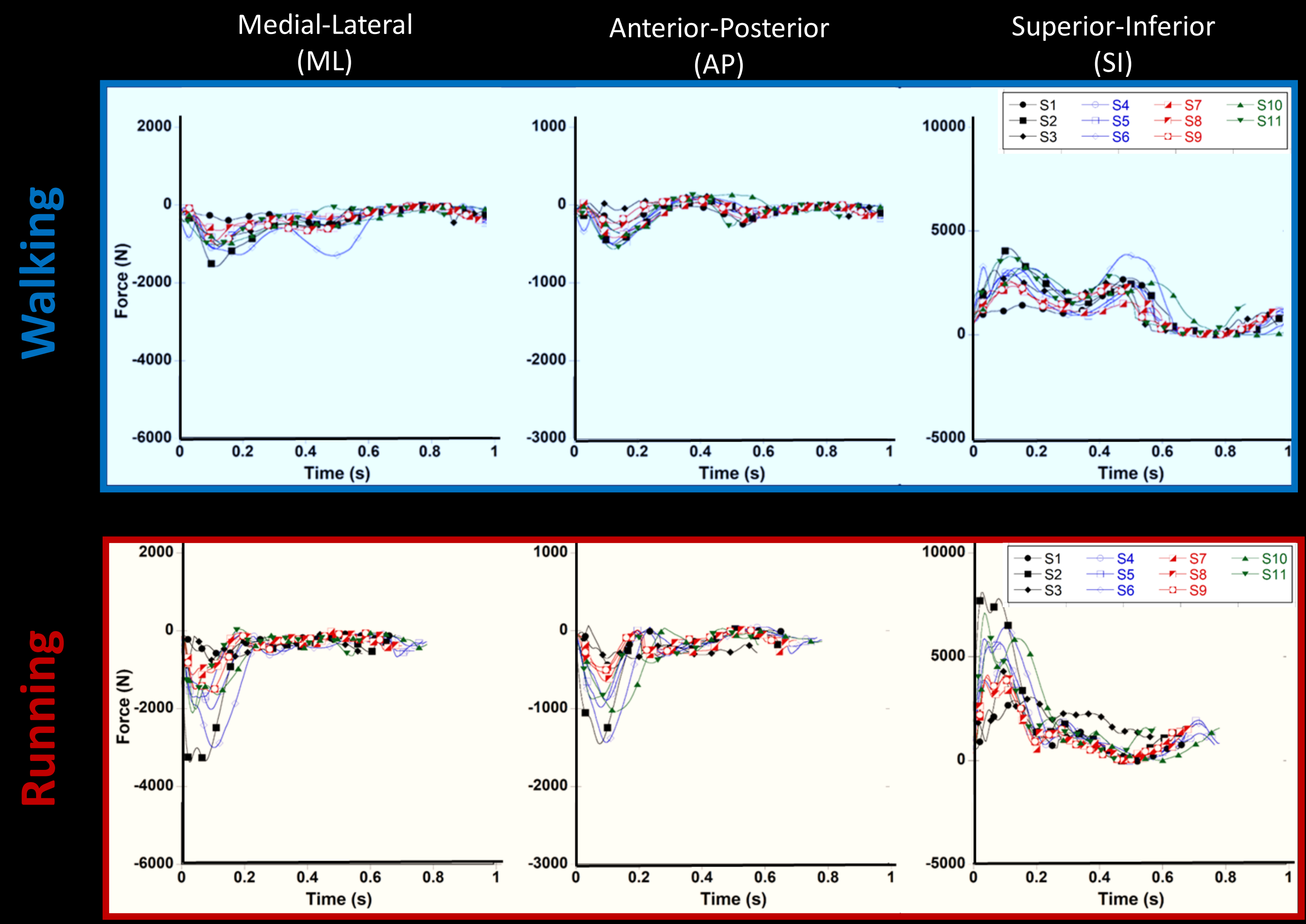
Linear wear depth
Wear rate (mm/Mc)
Volumetric wear (mm^3/Mc)
Contact area & pressure





ESTIMATED JOINT REACTION FORCES

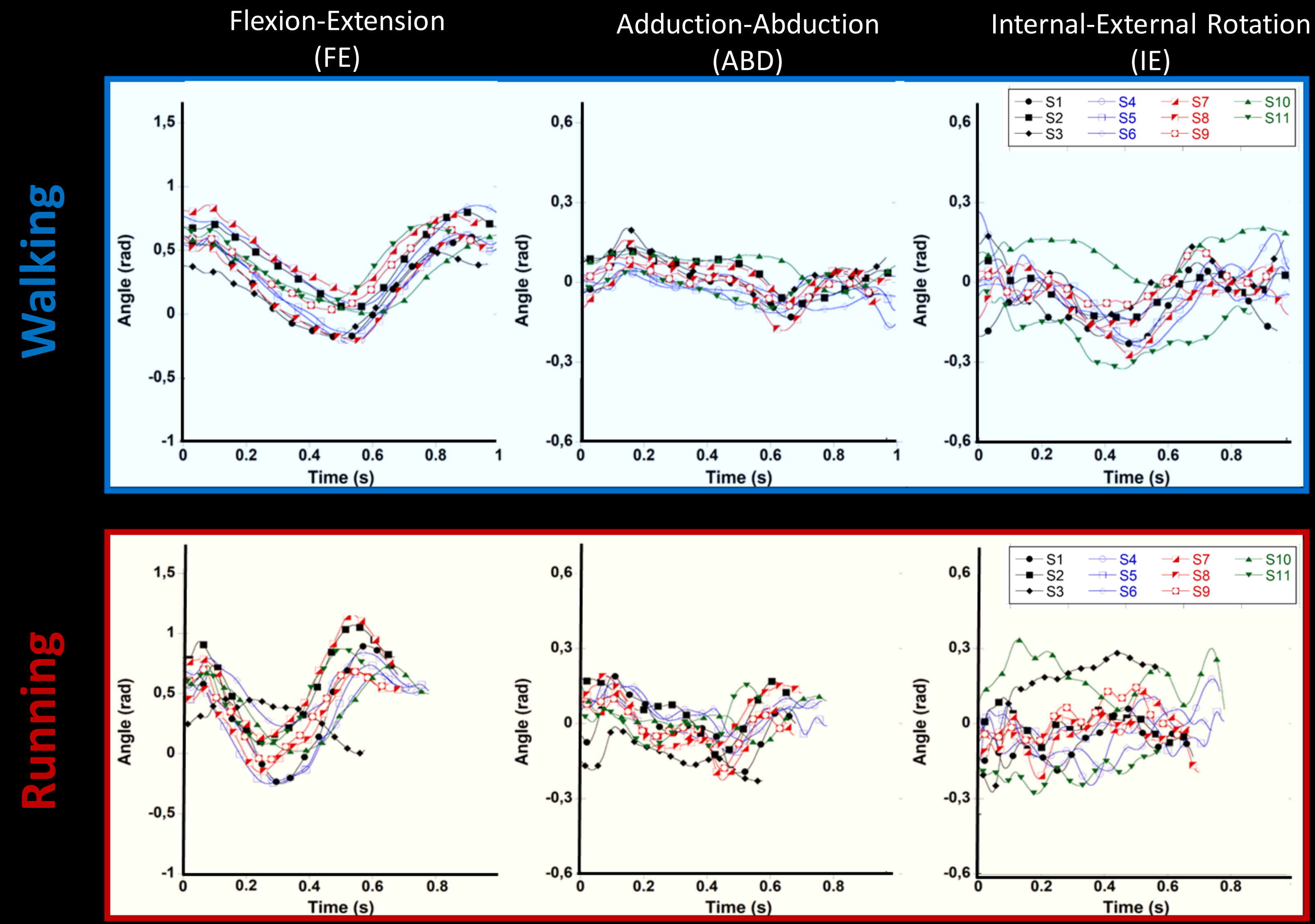
Refer to Bernard's presentation session and time



Cyclic time normalised to 1 sec

ESTIMATED JOINT ANGELS

Refer to Bernard's presentation session and time



Cyclic time normalised to 1 sec

DYNAMIC FE MODEL

GEOMETRY

Parameter	Value
Head radius	16 mm
Cup liner bearing surface radius	16.05 mm
Cup liner thickness	4 mm
Cup shell thickness	3 mm

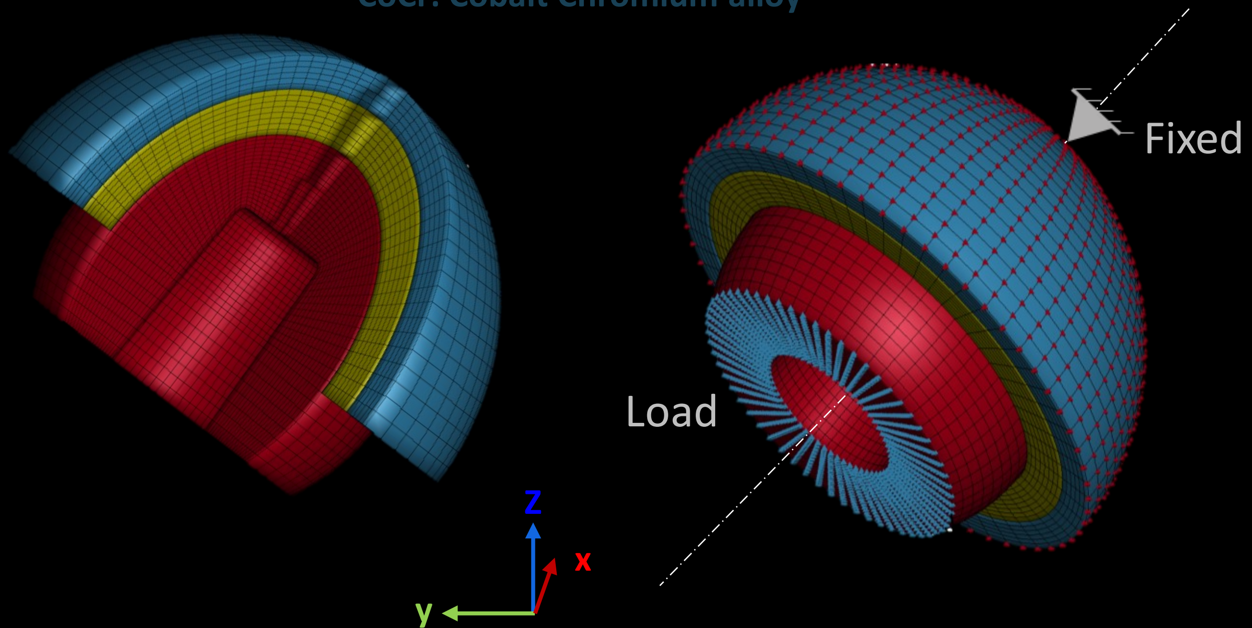
MATERIALS

Property [4]	XLPE (Liner)	CoCr (Shell)
Young's modulus (GPa)	1	210
Poisson's ratio	0.4	0.3
Density (kg/m³)	963	7800
Hardness (MPa)	45.6	1193

ANSYS LS Dyna

XLPE: Crosslinked polyethylene

CoCr: Cobalt Chromium alloy



X-axis
Anterior-Posterior (AP)
Abduction/Adduction (ABD)

Y-axis
Medial-Lateral (ML)
Flexion/Extension (FE)

Z-axis
Proximal-Distal (PD)
Internal/External (IE)

[4] Ming Song, et al. 2021

Physics

Abrasive Wear

Governing Equation

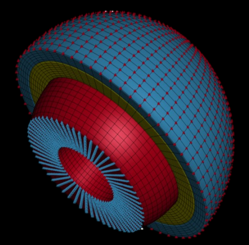
Archard wear law:

linear wear depth = $k\ p\ s$

Numerical Algorithm

$$V = \beta \sum_{i=1}^{N} k\ p_i s_i$$

FE model in LS-DYNA



V – incremental wear volume

β – number of activity cycles per update, β = 0.25 Mc

k – wear coefficient, k = 5.32 × 10^{-10} mm³/(N·mm)

p_i – contact pressure at mesh node i

s_i – sliding distance at mesh node i

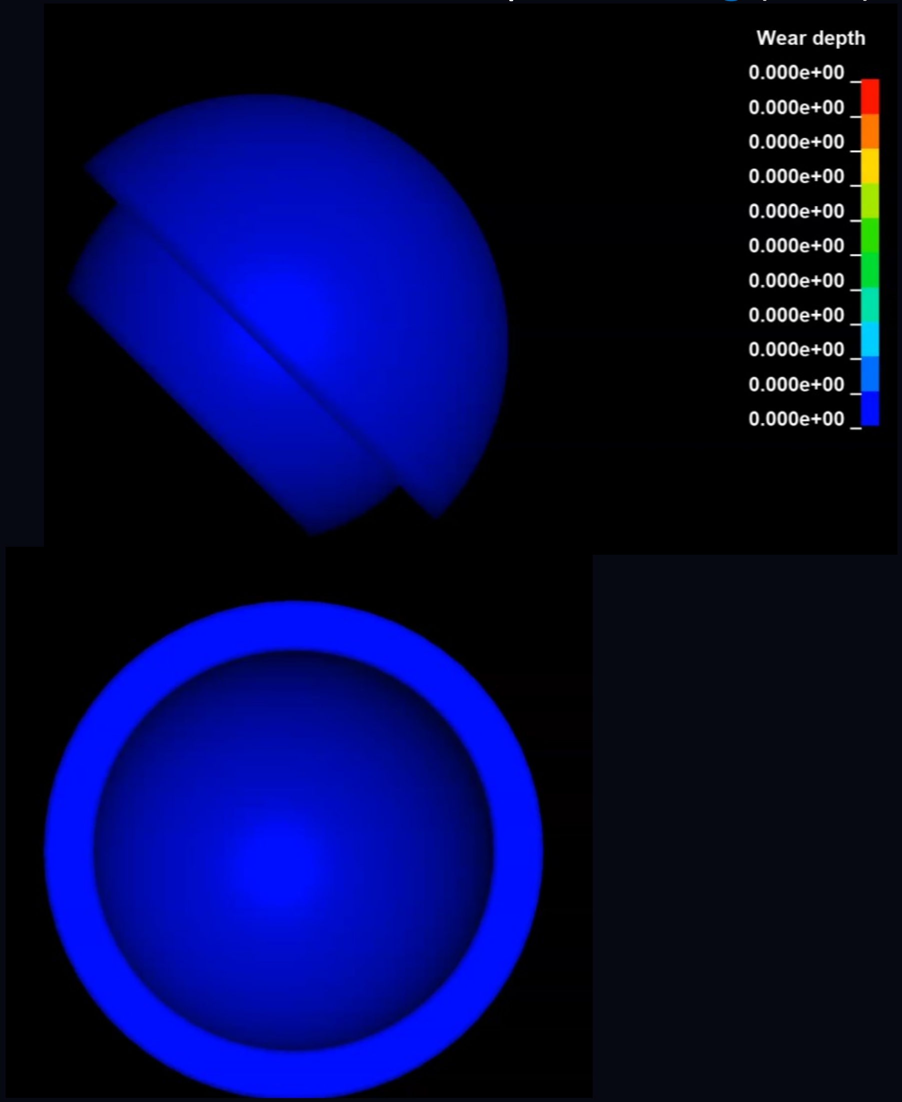
N – total number of element nodes

Limitations: factors not considered in the current wear model

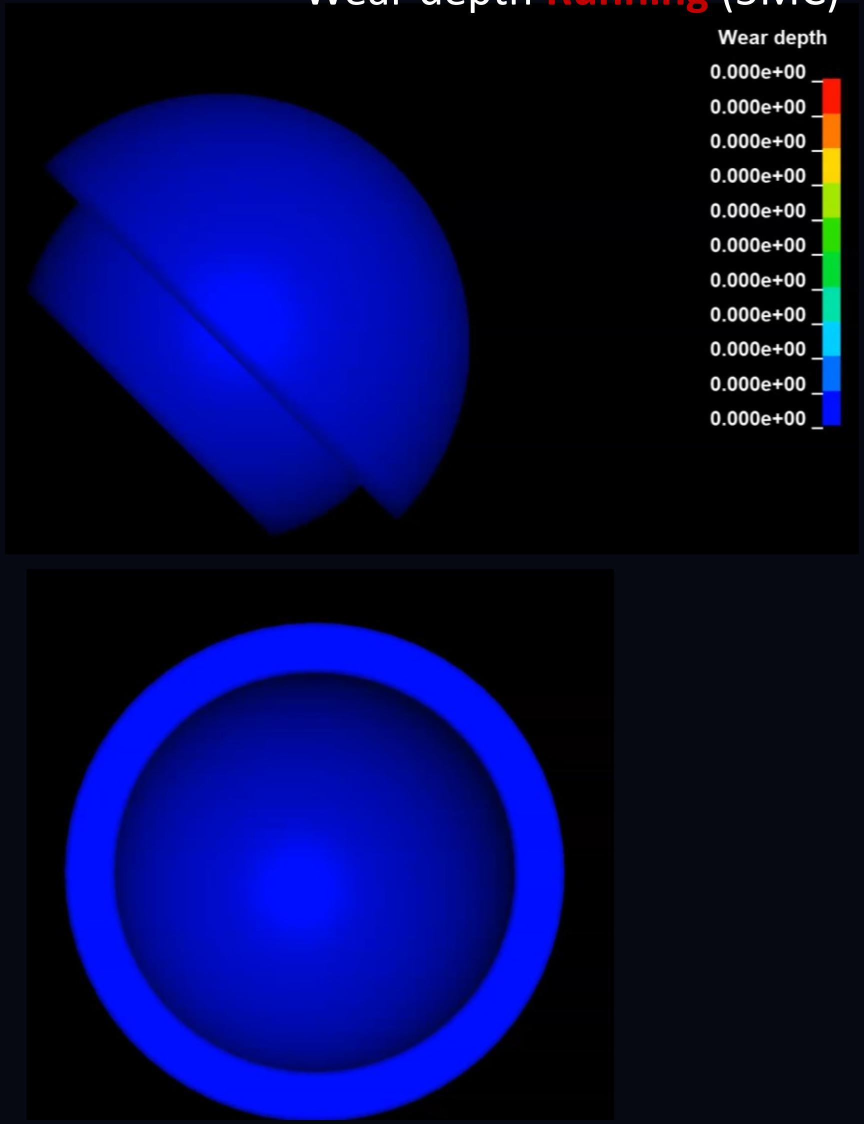
- Creep deformation
- Lubrication
- Surface roughness

[5] Matsoukas, G & Kim, 2009

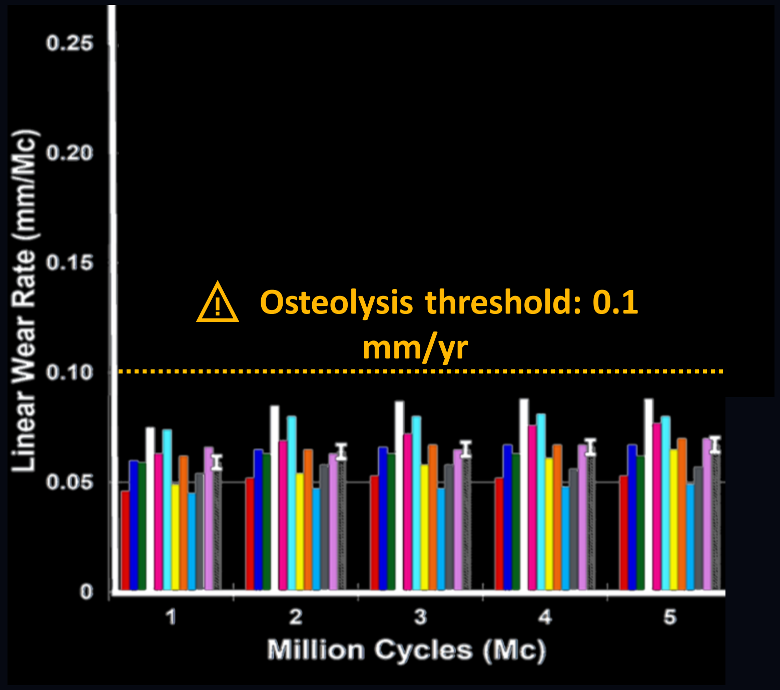
Wear depth **Walking** (5MC)



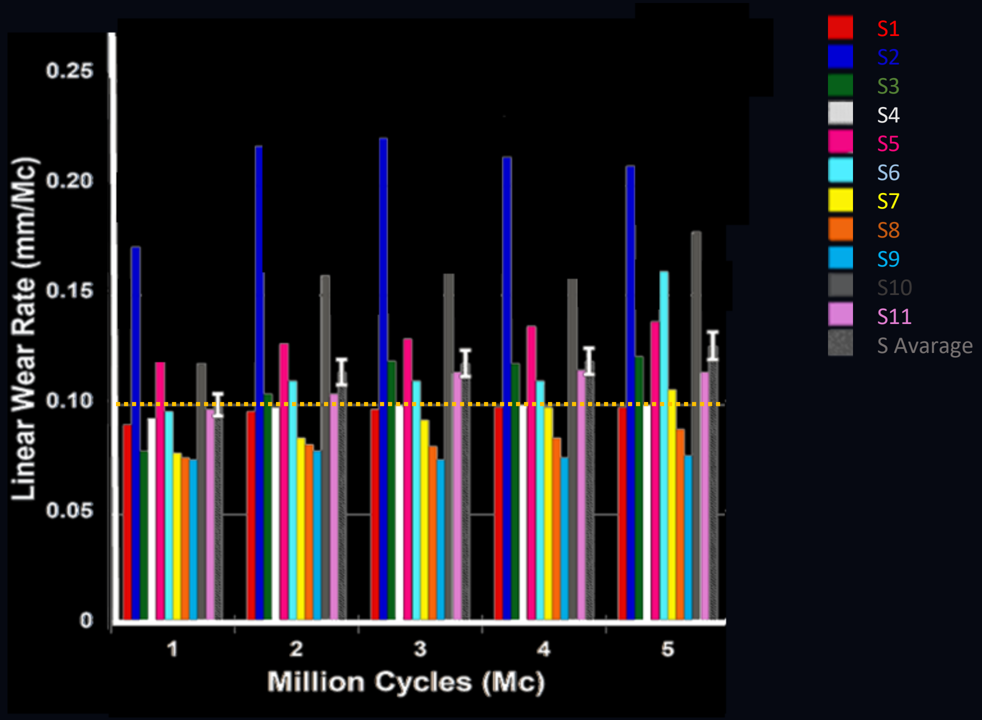
Wear depth **Running** (5MC)



Average linear wear rate



Walking 0.06 mm^3/Mc



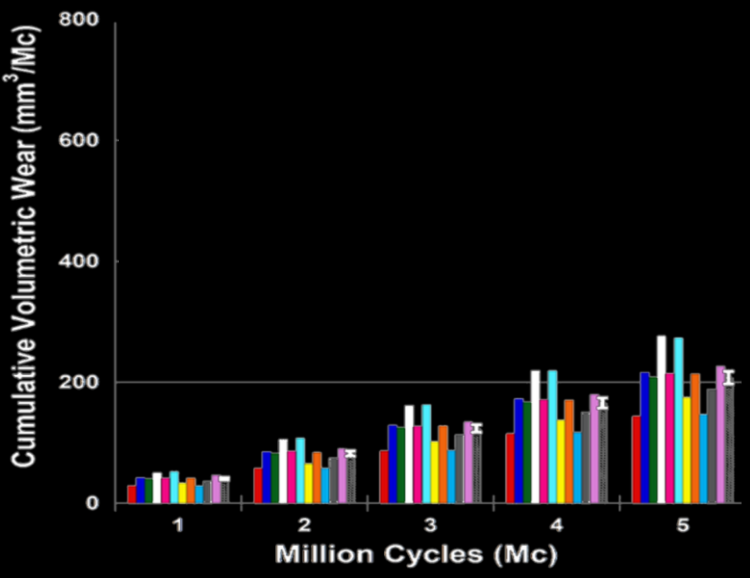
Running 0.12 mm^3/Mc

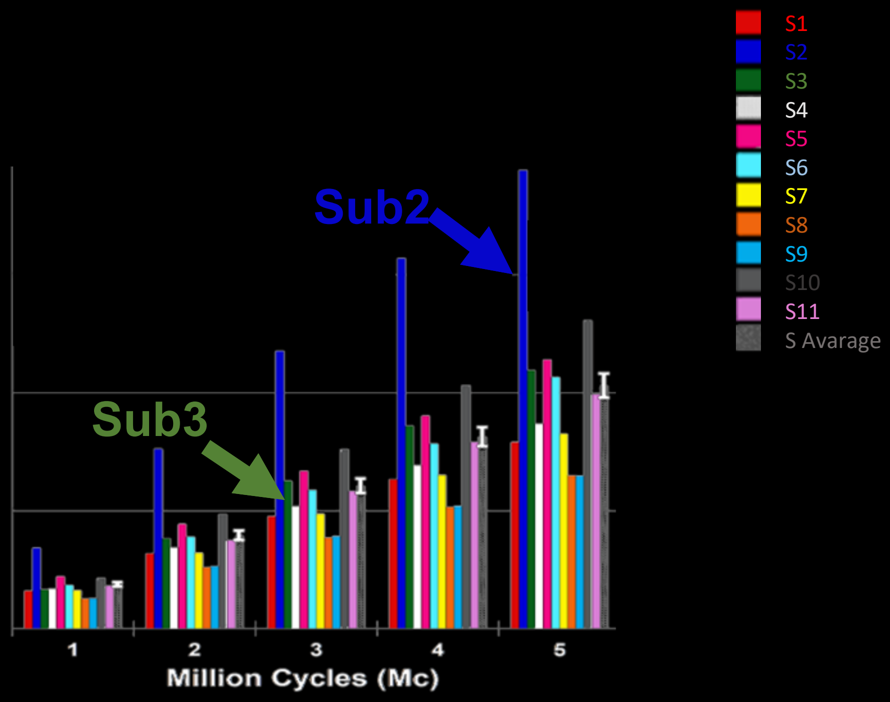
= ~2× walking

Clinical reported a wider range from 0.02 (HXLPE) to 0.17 [6]. Walking within clinical HXLPE range · Running exceeds osteolysis threshold

[6] Hopper et al., 2018

Mean cumulative volumetric wear





Walking 42 mm³/Mc

Cumulative walking wear of 5 Mc reached in only ~2.8 Mc of running

Running 82 mm³/Mc

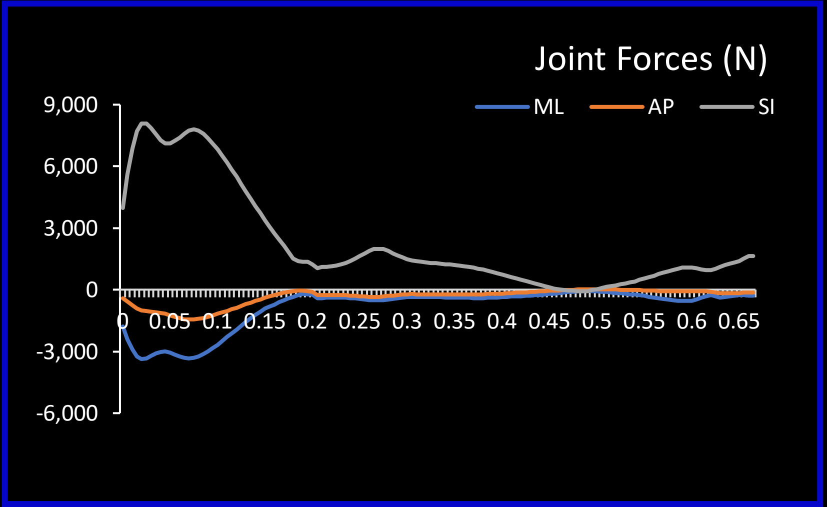
= ~2× walking

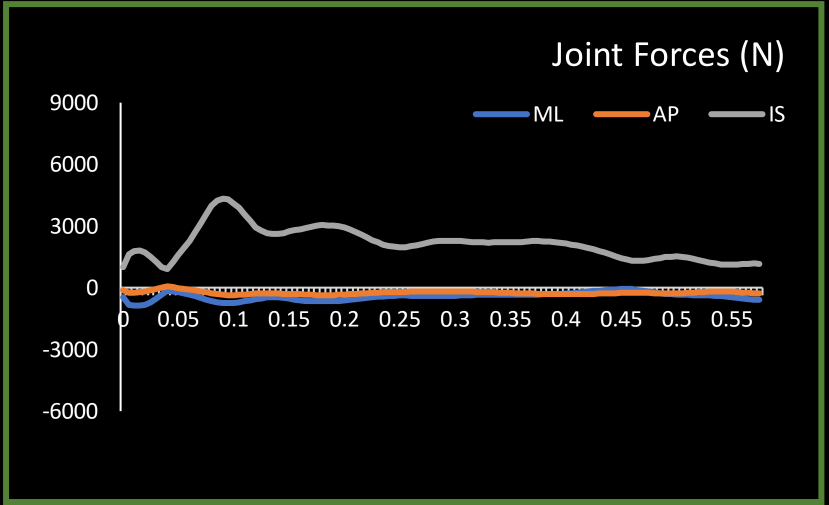
Why the difference between subjects? Mass or BMI? Joint loading? Rotation pattern?

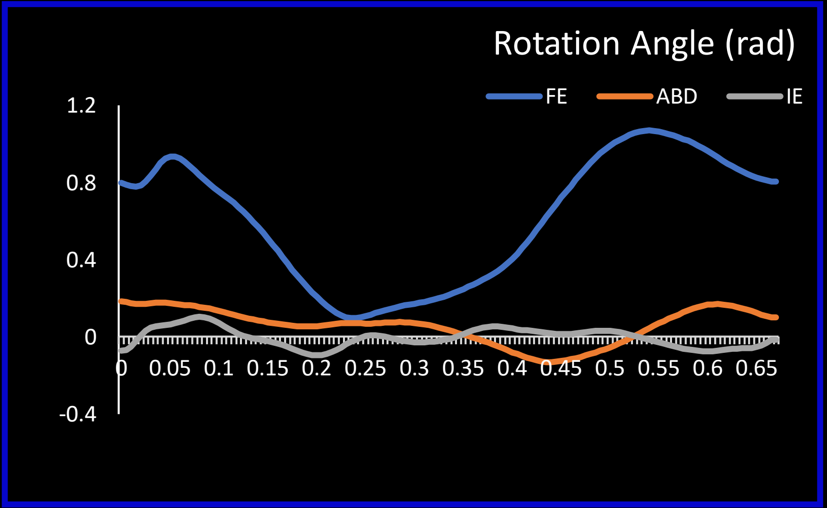
BETWEEN SUBJECTS

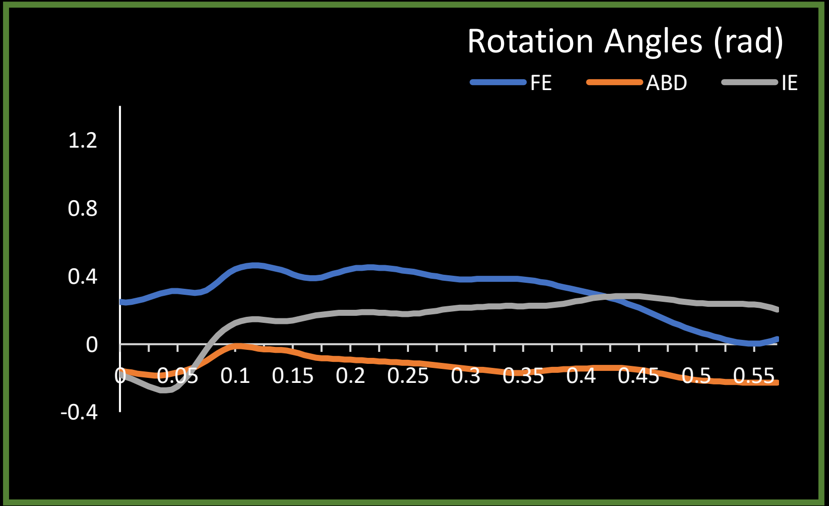
Subject 2: Mass 69; BMI 21.0

Subject 3: Mass 64; BMI 21.9









ID	Height	Mass	BMI
1	1.60	57	22. 3
2	1.81	69	21.0
3	1.70	64	21.9
4	1.78	62	19.6
5	1.75	73	23.8
6	1.79	78	24.3
7	1.68	65	23.0
8	1.76	61	19.7
9	1.68	58	20.5
10	1.82	91	27.5
11	1.72	81	27.4
Mean	**1.74**	**68.9**	**22.8**
SD	**0.07**	**10.7**	**2.8**

CROSS-COMBINATION SIMULATIONS: RATIONALE

*What drives inter-subject wear variability, **joint contact force magnitude**, or **rotational kinematics**?*

TWO OFF-TREND SUBJECTS IDENTIFIED

WALKING

- **S4** — High wear despite LOW body mass (62 kg)
- **S10** — Low wear despite HIGHER body mass (91 kg)

Forces broadly similar → rotational kinematics differ substantially
S4 has larger FE range and higher angular velocity than S10

RUNNING

- **S2** — High wear despite LOW body mass (69kg)
- **S11** — Low wear despite HIGHER body mass (81 kg)

Neither force nor kinematics alone explains S2's elevated wear
Likely driven by a unique combination of kinematic + kinetic conditions

METHOD:
Force and rotational kinematic inputs were swapped between selected subject pairs → four combinations per activity at 1 Mc → isolates the contribution of each factor

WALKING: S4 vs S10 (KINEMATICS DOMINATE)

Forces broadly similar → rotational kinematics differ substantially

Force	Rotation	Linear (mm)	Volume (mm³)	Δ
S4	S10	0.044	29.89	0% ref
S10	S10	0.054	36.60	+22%
S4	S4	0.075	50.52	**+69%**
S10	**S4**	0.085	57.70	**+93%**

WALKING

S4 — **High wear** despite **LOW body mass** (62 kg)
larger FE range and higher angular velocity

S10 — **Low wear** despite **HIGHER body mass** (91 kg)
lower FE range and lower angular velocity

S4's rotation pattern alone drives +93% more wear *regardless of which subject's force profile is applied*

WHY?

Under Archard's law, wear ∝ contact pressure × sliding distance. A larger FE rotation range → greater sliding distance per cycle → elevated wear. Greater multidirectional motion also raises the cross-shear ratio, which is itself a known driver of XLPE wear. In S4, these kinematic effects outweigh the body mass advantage.

RUNNING: S2 vs S11 (COMBINED KINEMATIC–KINETIC EFFECT)

Forces Neither force nor kinematics alone explains S2's elevated wear, likely driven by a unique combination of kinematic + kinetic conditions

Force	Rotation	Linear (mm)	Volume (mm^3)	Δ
S11	S11	0.098	72.58	0% ref
S2	S11	0.109	81.79	+13%
S11	S2	0.149	114.95	**+58%**
S2	**S2**	0.172	136.61	**+88%**

RUNNIG

S2 — **High wear** despite **LOW body mass** (62 kg)

FE range and angular velocity were relatively similar

S11 — **Low wear** despite **HIGHER body mass** (91 kg)

S2 rotation adds +58% wear (vs +13% for S2 force alone) *kinematic contribution is 4.5× larger than the force contribution*

Key Takeaway:

- Swapping rotation patterns produced far greater wear changes (up to +93%) than swapping force profiles (up to +22%).
- Rotational kinematics, not body mass or contact force magnitude, are the primary modifiable driver of inter-subject wear variability.

To conclude:

- Running produced approximately two-fold wear than walking
- Dynamic joint loading and rotation angles during running vary significantly between individuals that substantially affect wear
- Use of subject-specific, activity-dependent FE frameworks for implant wear assessment is important

Thank you!

CHECKOUT Safejoints

https://safejoints.netlify.app/

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