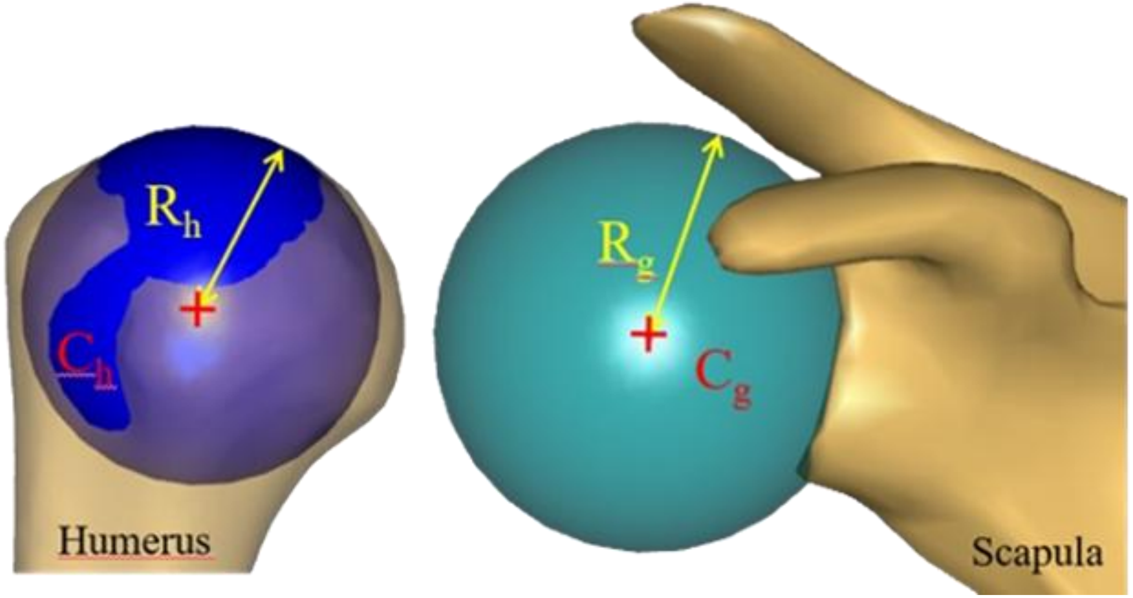
ANYBODY TECHNOLOGY

January 15, 2026

Sphere-on-Sphere model

Shoulder model including humeral head translation



The webcast will begin shortly...

Outline

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

Presenter

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Host

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Biomechanical Specialist

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dsc@anybodytech.com

AnyBody Technology

Outli | ontrol Panel | AnyBody | Presentation | Events | Q&A

Outli

- In... ystem


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Effect of congruence variations on a musculoskeletal model considering humeral head displacements

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ARTICLE INFO

Keywords:
Musculoskeletal shoulder model
Humeral head displacement
Rotator cuff muscles
Force-dependent kinematics
Congruency

ABSTRACT

The shoulder's large range of motion is due to the low congruency of the glenohumeral joint, whose stability relies mainly on rotator cuff muscle activity. The effect of joint congruence on shoulder biomechanics remains unclear. We used a sphere-on-sphere glenohumeral model combined with a Force-Dependent Kinematics algorithm to simulate muscle and joint forces while considering humeral head displacements. Our innovative simulations showed an increase in humeral head displacements and rotator cuff muscle forces when joint conformity decreased. Our model aligns with in vivo observations and highlights the importance of joint congruence on stability. It provides insights to improve our understanding of shoulder biomechanics.

1. Introduction

The shoulder's wide range of motion stems from scapula gliding on the thorax and the low congruency between the glenoid and humerus, with rotator cuff muscles providing active joint stabilization (Veeger and van der Helm, 2007). While in vivo studies report up to 12.4 mm superior humeral head migration during abduction (Dal Maso et al., 2014), most musculoskeletal models use ball-and-socket joints with three rotational degrees of freedom (DoF). To effectively address clinical questions, models must consider humeral head displacements ...

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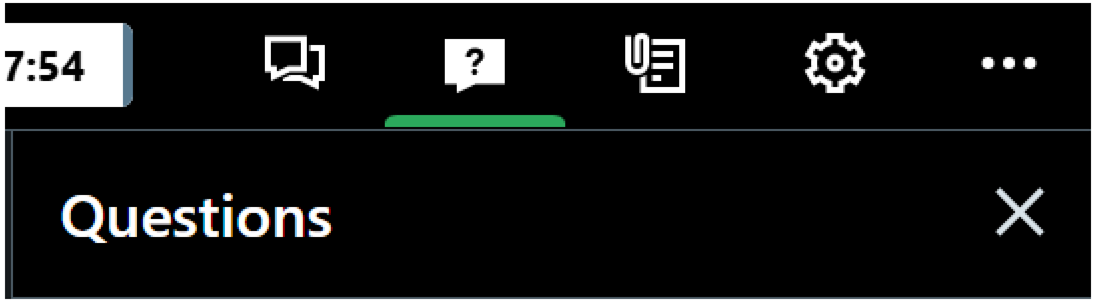
Control Panel

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

Submit questions and comments via the Questions panel.

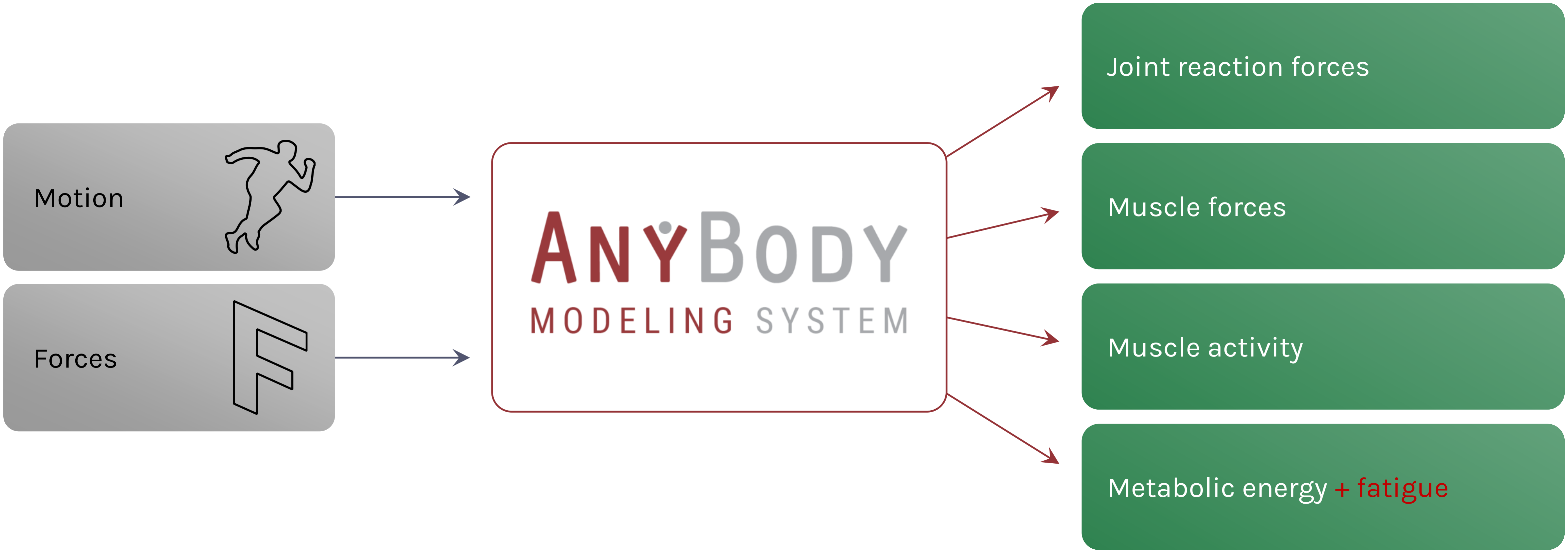


Questions will be addressed at the end of the presentation. If your question is not addressed, we will do so by email.

Musculoskeletal simulations

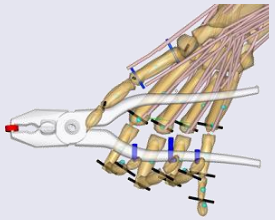
INPUT • Motion data

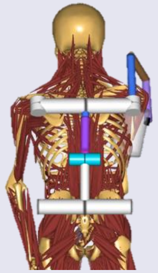
OUTPUT • Internal Body Loads



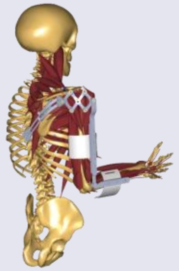
Motion analysis

Product design and optimization

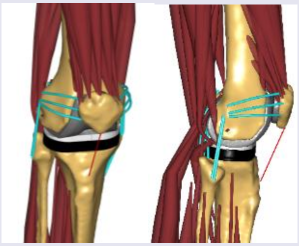




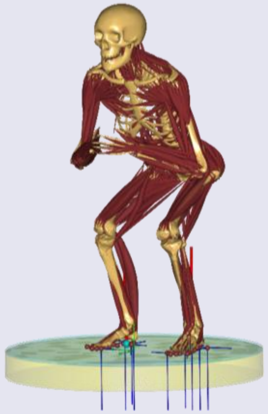
Ergonomics with/without exoskeletons



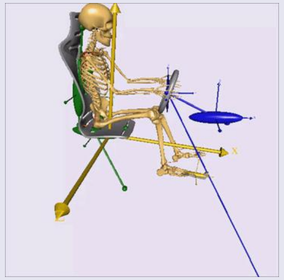
ANYBODY
MODELING SYSTEM



Orthopedics and Rehabilitation



Sports

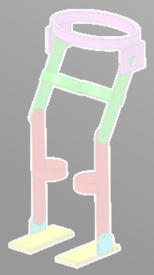


Automotive

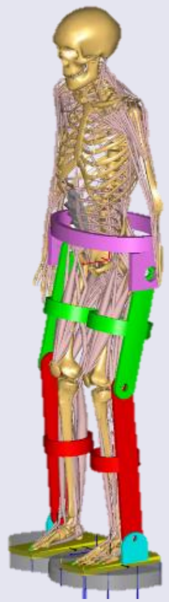
Workflow

Motions and forces

Body model

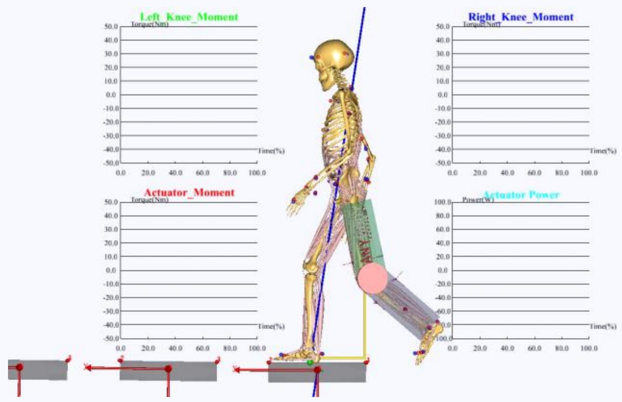


Environment model



Simulation

Inverse dynamics
Muscle recruitment



Internal body loads:

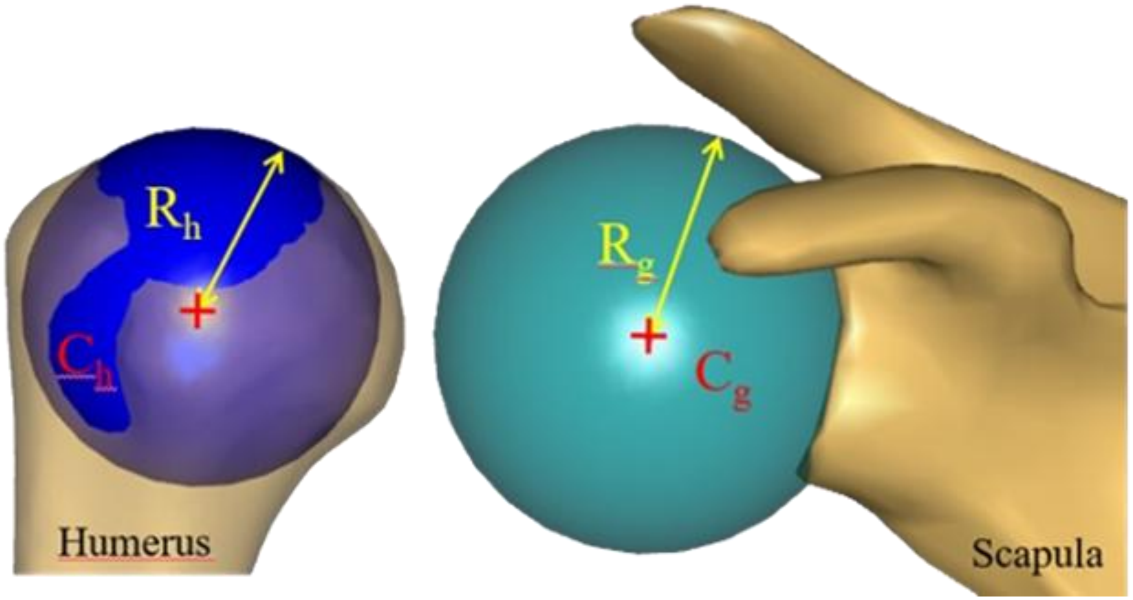
- Muscle forces
- Joint forces

Design Optimization

Post Processing
(e.g. Finite Element tools)

Sphere-on-Sphere model

Shoulder model including humeral head translation

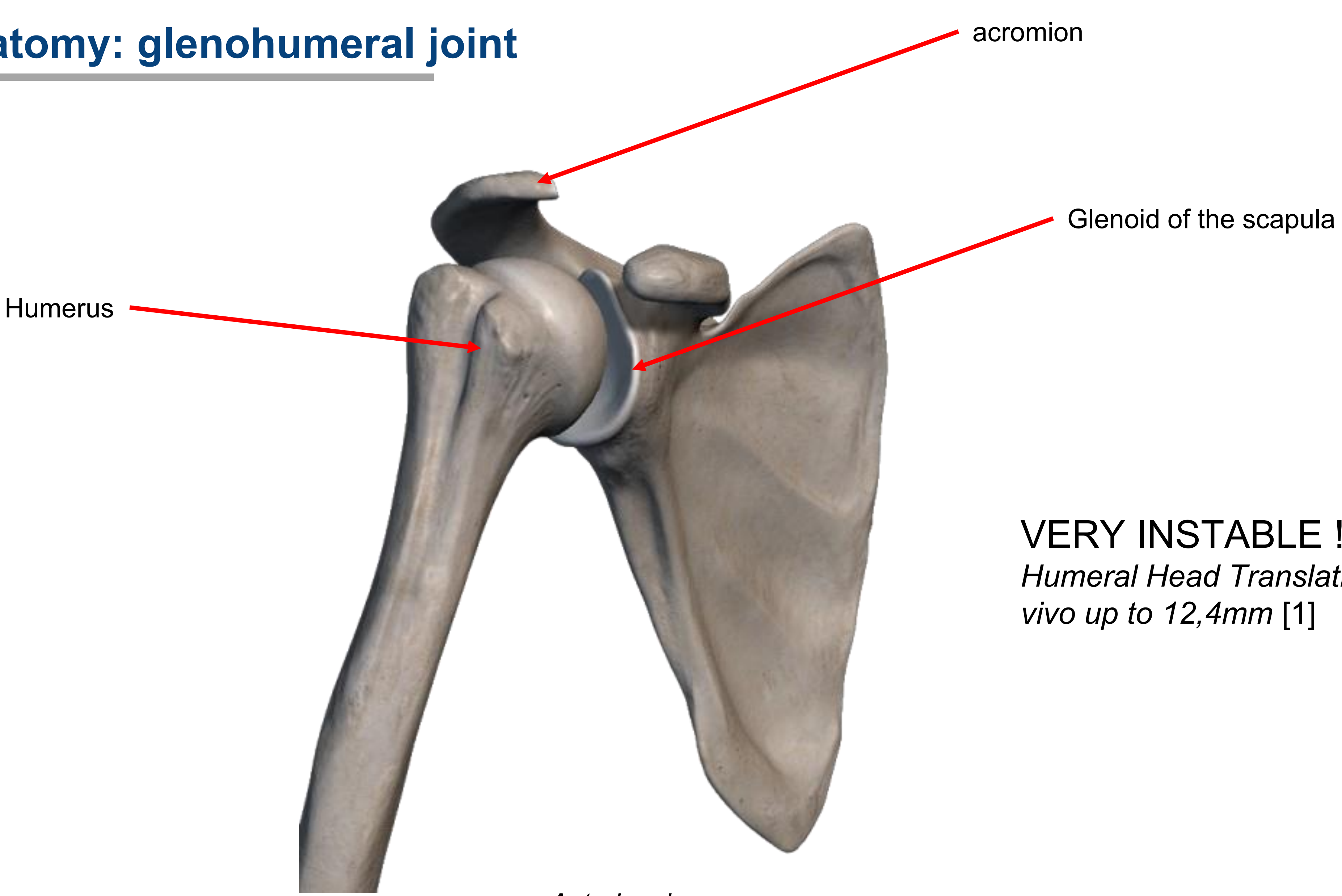


SPHERE-ON-SPHERE MODEL: SHOULDER MODEL INCLUDING HUMERAL HEAD TRANSLATION

Musculoskeletal modeling of the shoulder to understand the mechanisms of injuries influenced by scapular and humeral geometry.

Margaux Peixoto, PhD candidate – École de Technologie Supérieure
Nicola Hagemeister – École de Technologie Supérieure
Mickaël Begon– Université de Montréal

Shoulder anatomy: glenohumeral joint



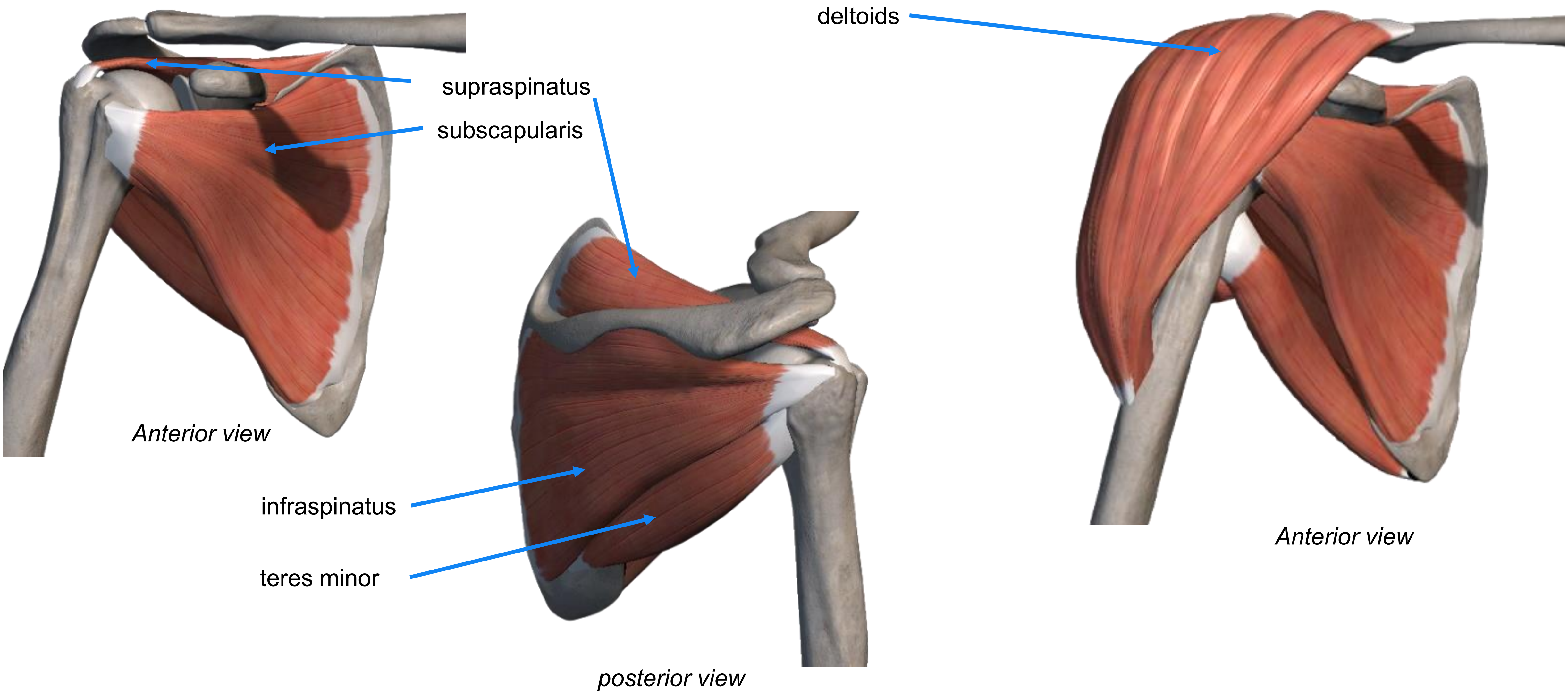
Anterior view

VERY INSTABLE !

Humeral Head Translations: in vivo up to 12,4mm [1]

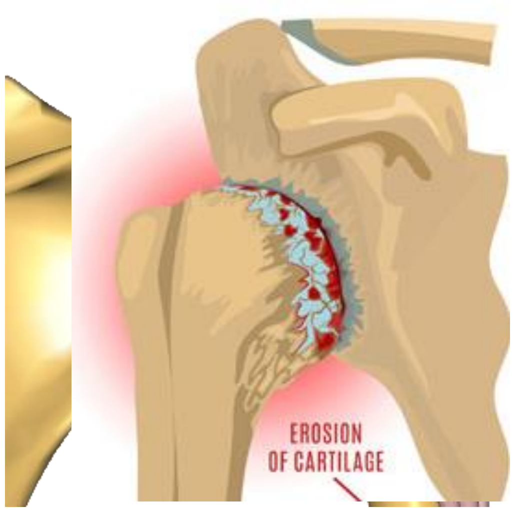
[1] Dal Maso et al. (2014)

Shoulder anatomy: glenohumeral muscles

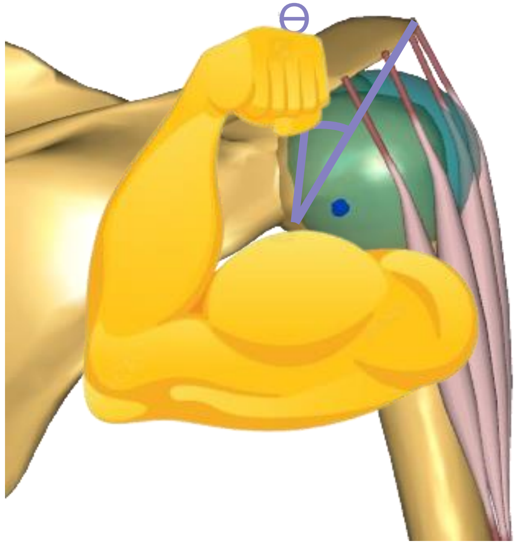


Context | Link between pathology and morphology

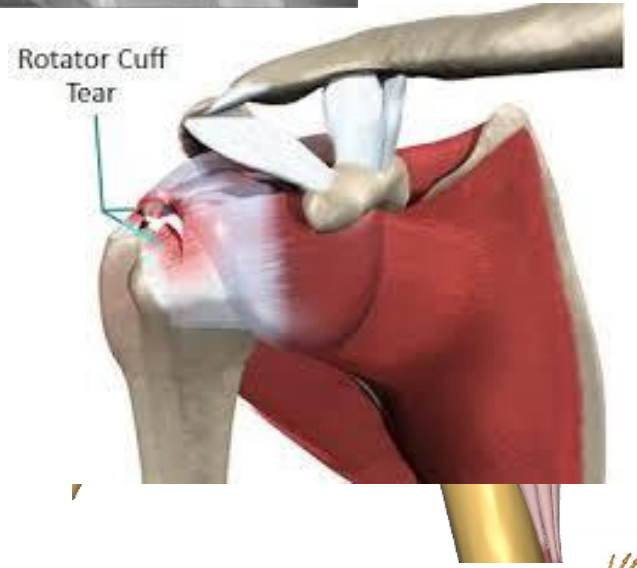
Etiology of the shoulder pathologies : impact of scapula morphology?
*New parameter : **Critical Shoulder Angle** [1]*



small CSA (<28°):
osteoarthrosis



normal CSA (33°):
healthy joint

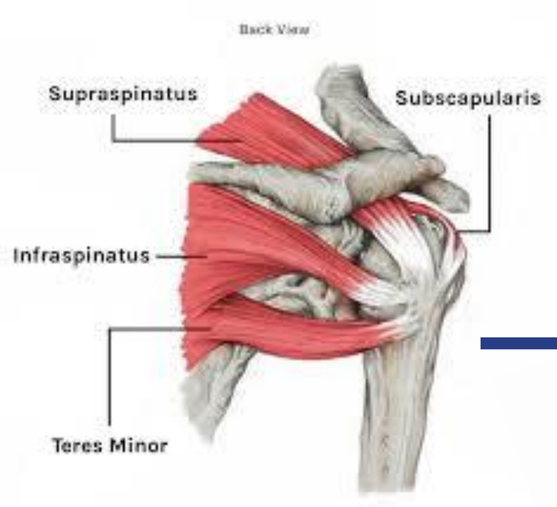


large CSA (>38°):
rotator cuff tears

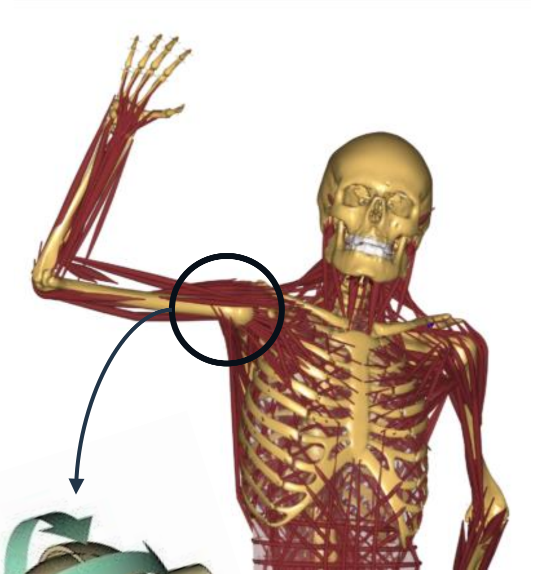
→ *Biomechanical study with musculoskeletal models*

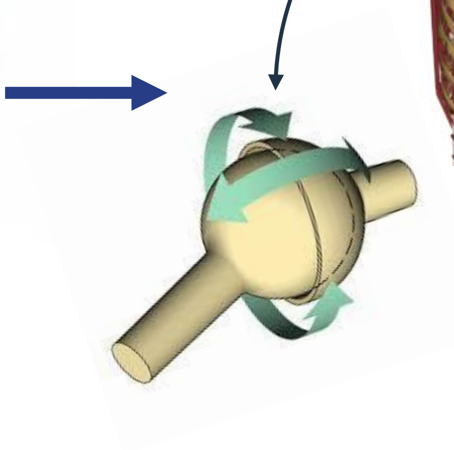
[1] Moor et al. (2013)

Context | Modeling challenges



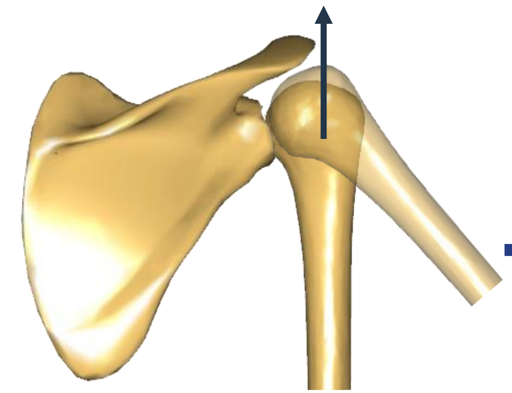
Complex stabilization mechanisms (passive + active) [1]



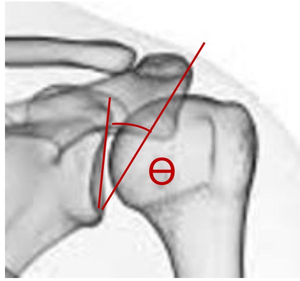


Ball-and-socket (3 DoF)

~~Humeral head displacements~~
~~*In vivo : up to 12.4 mm [2]*~~



Non physiological activation of the cuff muscles



Difficult to assess the effect of bone morphology on shoulder biomechanics

We therefore need a model representing the displacements of the humeral head!

[1] Veeger and Helm (2007)
[2] Dal Maso et al. (2014)

Main objectif

Objectif: *To develop a model allowing for humeral head translation to study the relationship between shoulder bones morphology and pathomechanisms.*

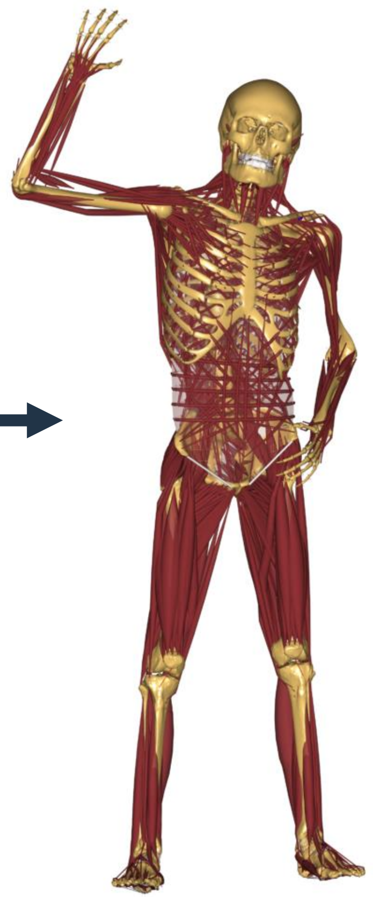
“Does the morphology of the bones influence the tendency to develop specific shoulder pathology ?”

Litterature review | Muskuloskeletal model

Inputs

- Bones geometry
- Muscles geometry
- Kinematic
- External forces

Musculoskeletal model



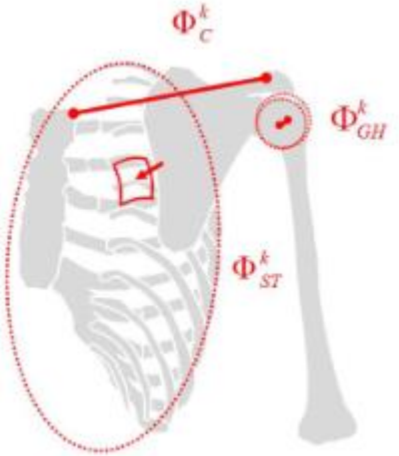
https://www.anybodytech.com/

Outputs

- Joint reaction force
- Muscular forces
- Humeral head translation ?

Sphere-on-sphere representation [1]:

- Geometrical constraint
- Kinematic model only

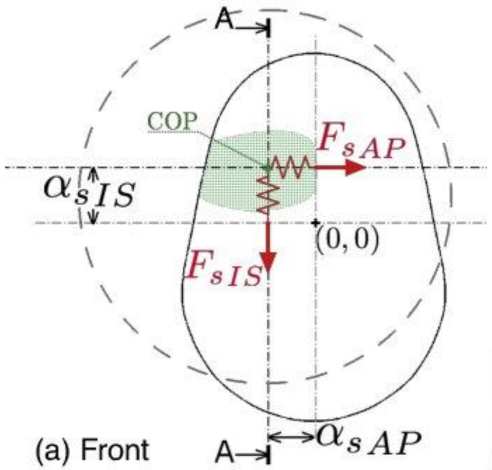


$$\|C_g - C_h\| = (R_g - R_h)$$

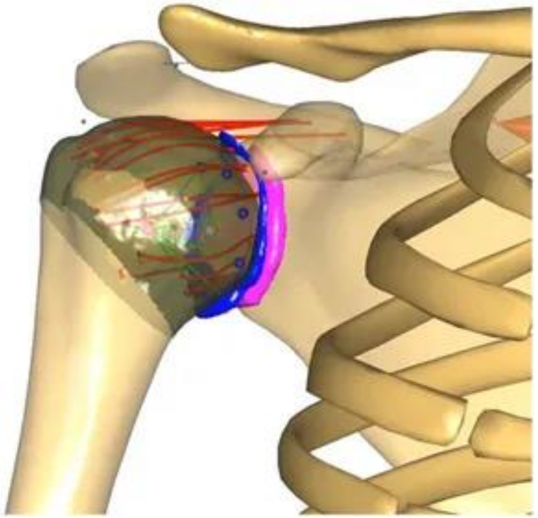
El Habashi (2015)

FDK algorithms solution:

- Arthroplasty [2]
- Healthy [3]
- Arthroplasty + RCT [4]
- RCT [5]



Sins (2014)



Menze (2025)

BUT additional springs needed

→ GH stability is not assured by the cuff muscles

[1] El Habachi et al. (2014)
[2] Sins et al. (2014)
[3] Aurbach et al. (2020)
[4] Lee et al. (2023)
[5] Menze et al. (2025)

1rst specific objectif

Objectif: *developing a 5 Degrees-of-Freedoom (DOF) shoulder model with physiological activation of the cuff muscles.*

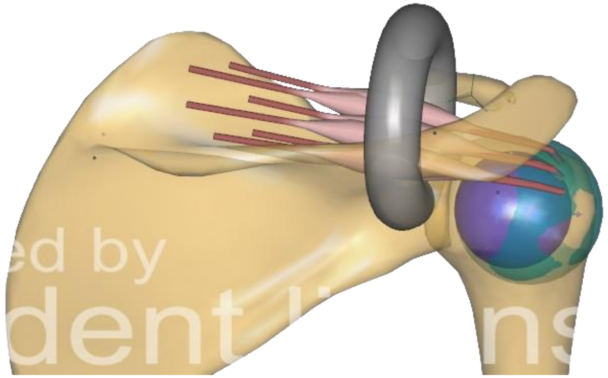
Research question: *"How does Critical Shoulder Angles (CSAs) variations affect the biomechanics of the joint in a musculoskeletal shoulder model with humeral head displacement?“*

Hypothesis: *By releasing DOF, cuff muscles activation will increase to stabilize the joint. Large CSA will have higher instability and therefore higher activation from the cuff muscles.*

Method | Shoulder model

The Anybody Shoulder Arm model:

- 118 fiber muscles (Hill) [1]
  →individuals wrapping objects
- Parameters from the Dutch Shoulder Group [2]
- Scapulohumeral rhythms [3]
  →coupling scapula to humeral motion

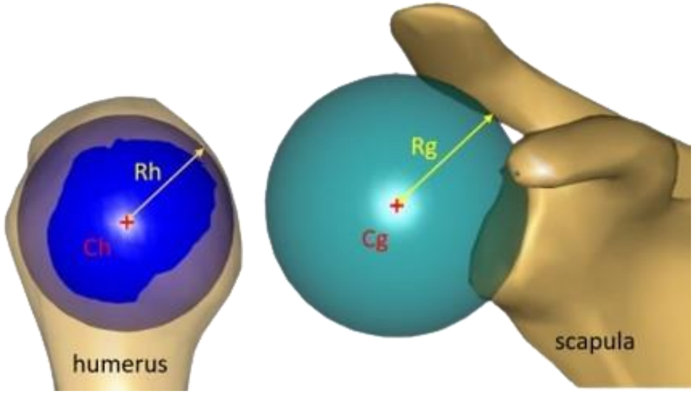


Additionals modifications:

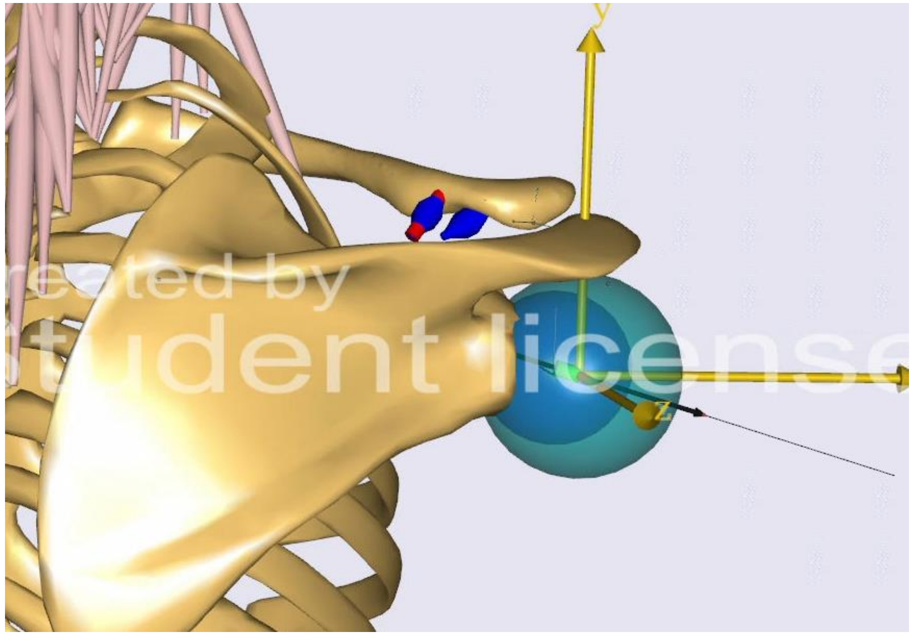
- Additional supraspinatus wrapping object (torus)
- Corrected subscapularis insertion position

[1] Zajac. (1989)
[2] Helm et al. (1992)
[3] de Groot et al. (2001)

Method | Sphere-on-Sphere FDK model



Rh = 23.6 mm,
Rg = 31.6 mm [1]



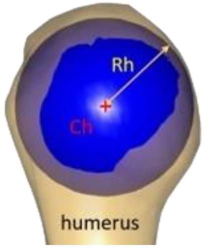
Based on Anybody 8.0,4 (AMMR 3.0.4) [2]
Available on Github: 10.5281/zenodo.17279962

	$\min_{\beta, a_i, T_{GH}} \left(\beta + \omega \sum_{i=1}^{n} {a_i}^2 \right)$	**Cost function**	**1a**
s.t.	$\beta \geq a_i$	β-defining constraint (min/max load sharing)	1b
	$0 \leq a_i \leq 1$	Physiological activations bounds	1c
	$\mathrm{R}\,(\theta, \mathrm{T}_{GH}). f_m(a_i) = \tau$	Inverse dynamics constraint	1d
	$\lVert C_g - C_h \rVert = (R_g - R_h)$	Glenohumeral SoS constraint [3]	1e
	$f_{FDK}(T_{GH}, a_i) < 1\ \mathrm{N}$	Glenohumeral FDK [4]	1f

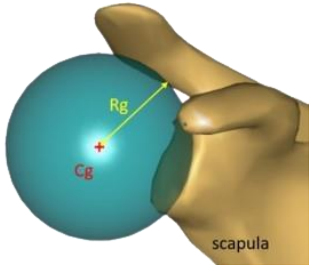
- ω=1: weight to ponder quadratic auxiliary term.
- *n*: number of muscles
- C_g, C_h and R_g, R_h the center and radii of the glenoid and humeral head, respectively.
- R: moment arm matrix (function of abduction angle θ and humeral head translation (T_{GH}) resulting from the FDK optimization problem)
- f_{FDK}: FDK residual forces

[1] Yamani et al. (2022)
[2] Lund et al (2023)
[3] El Habashi et al. (2015)
[4] Andersen et al. (2017)

Method | Acromion length variations



Rh = 23.6 mm;

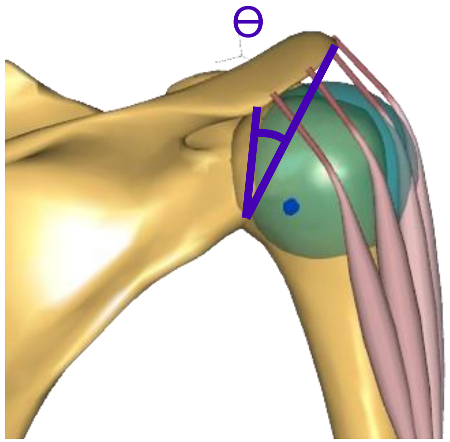


Rg = 31.6 mm [1]

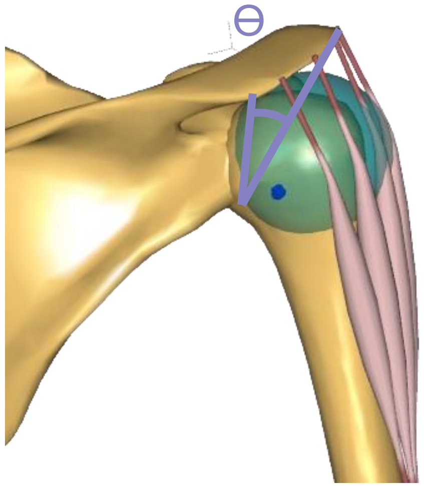
Simulation:
130° abduction in scapular plane

CSA variation by alteration of the position of the lateral deltoid muscle insertions

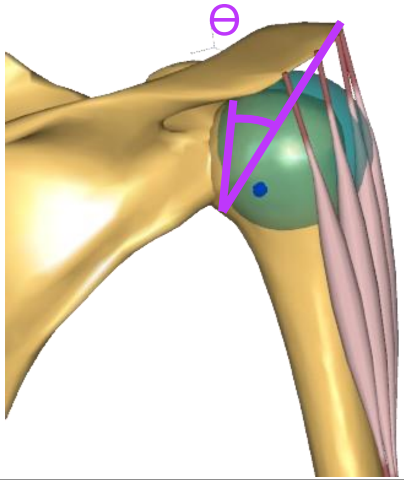
Short acromion : **CSA 28°**



Normal acromion: **CSA 33°**



Large acromion: **CSA 38°**

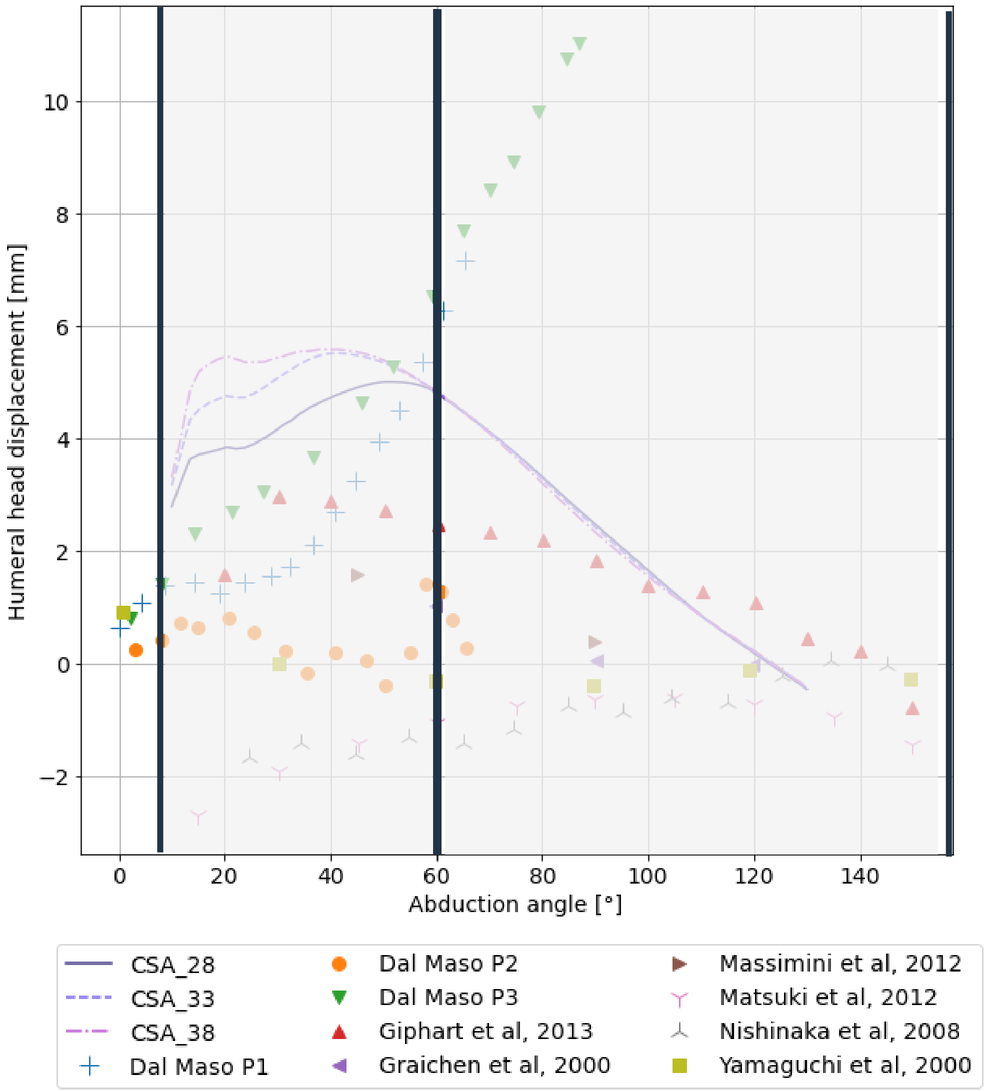


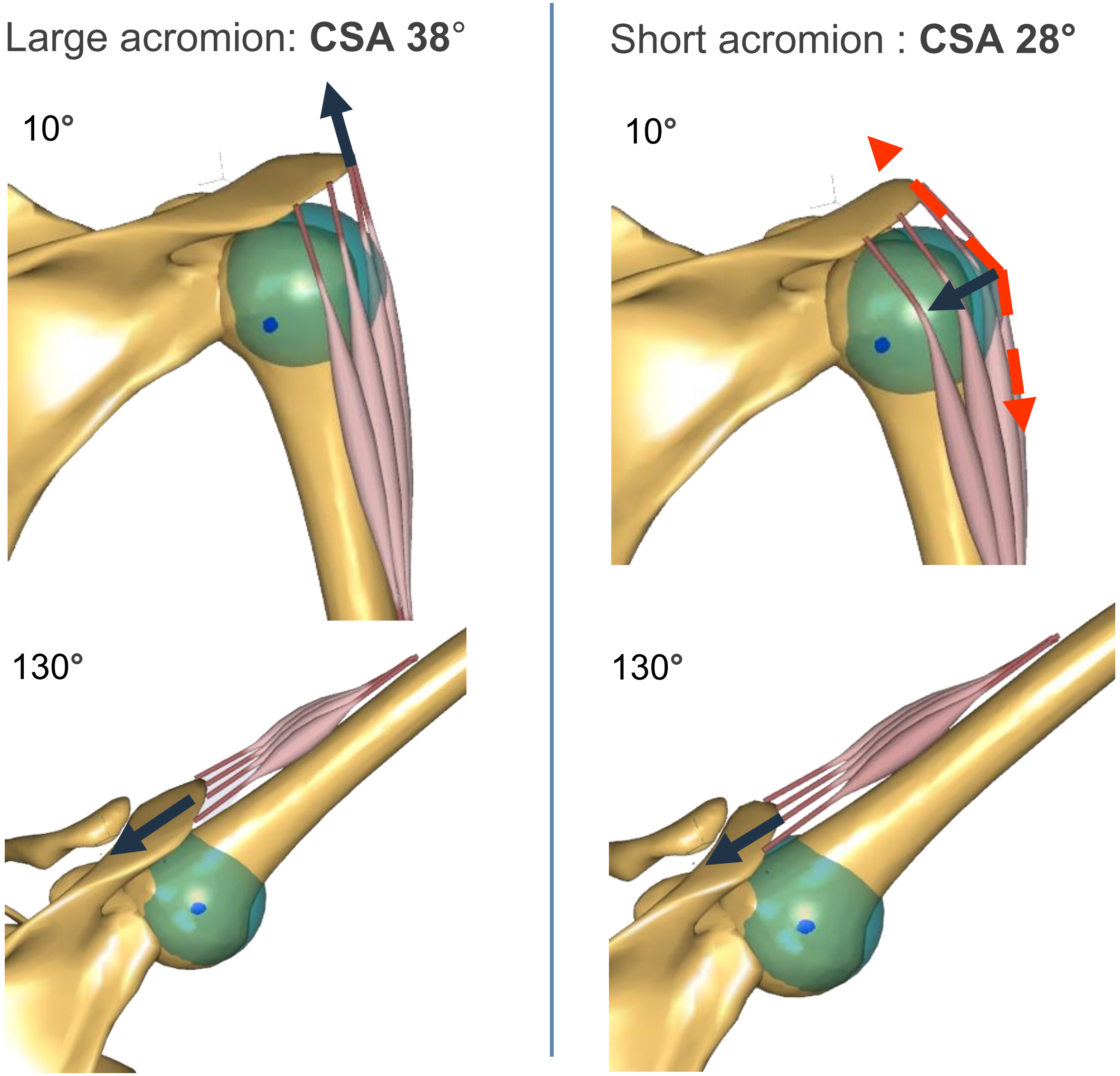
Outputs:

- Humeral head displacements
- Muscle forces
- Resultant forces (instability ratio)

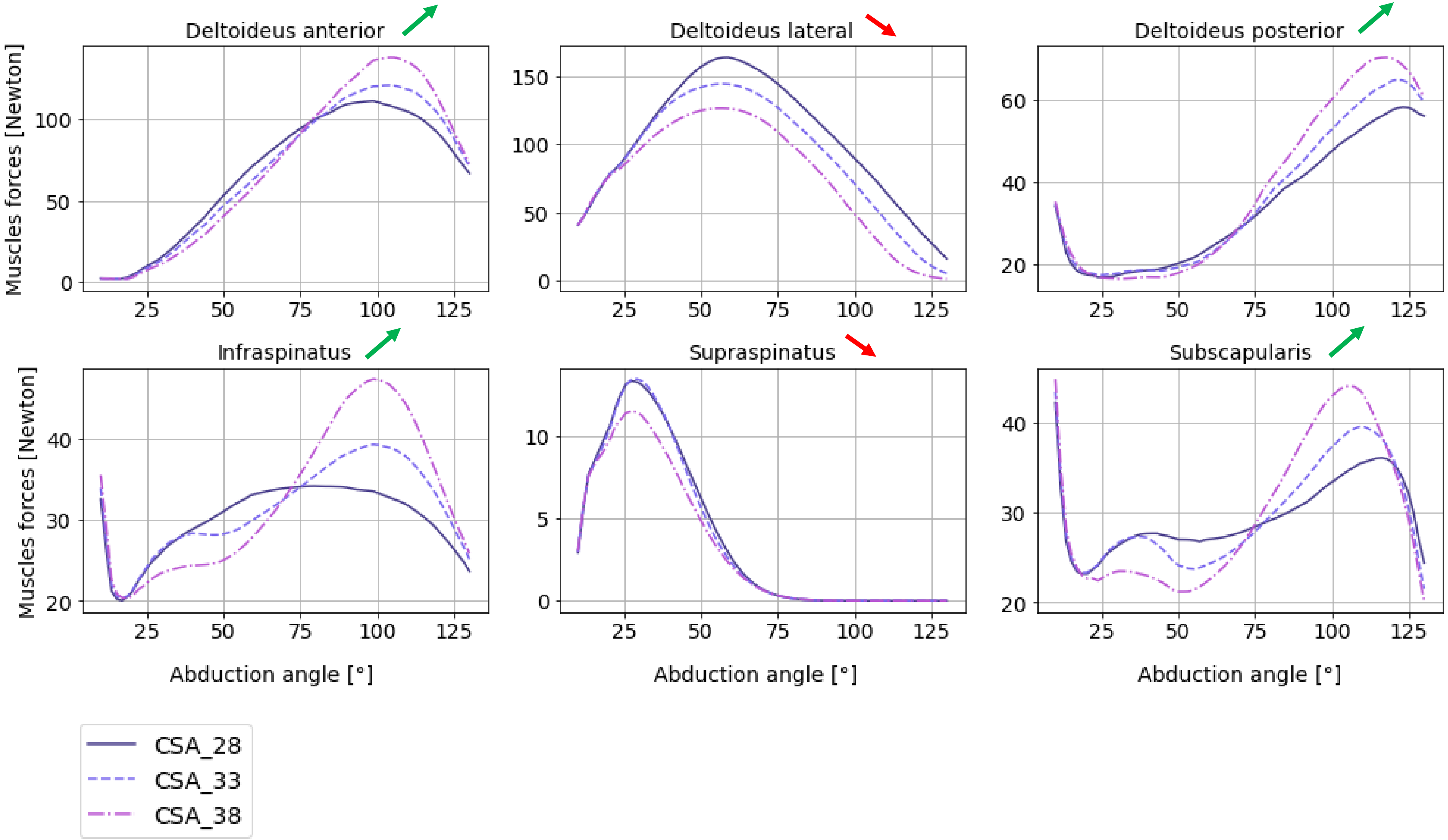
[1] Yamani et al. (2022)

Results | Humeral head displacment sensitivity to acromion length





Results | Muscles forces sensitivity to acromion length

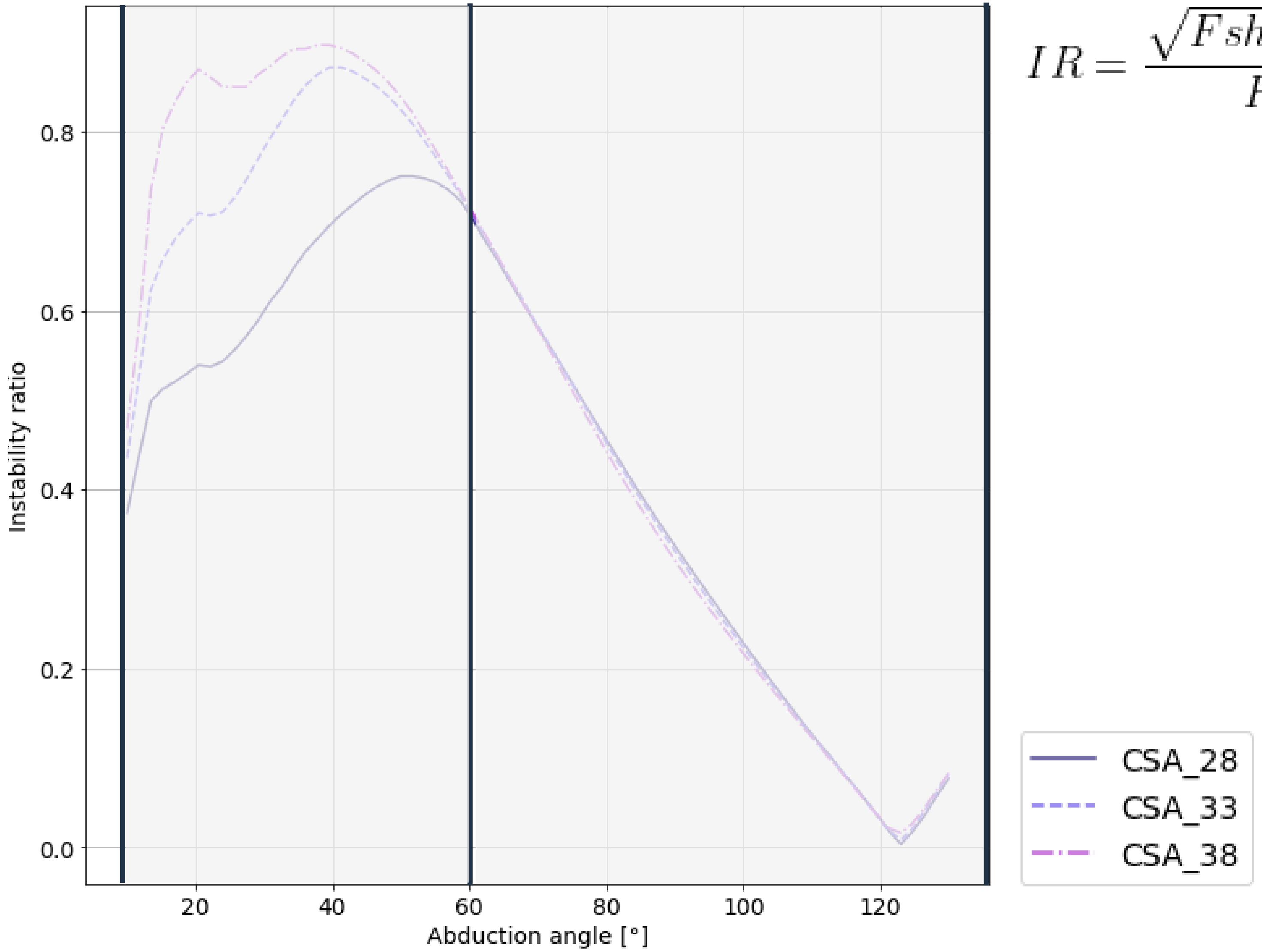


Stabilization :
Anterior and posterior deltoid, infraspinatus and subscapularis [1,2]

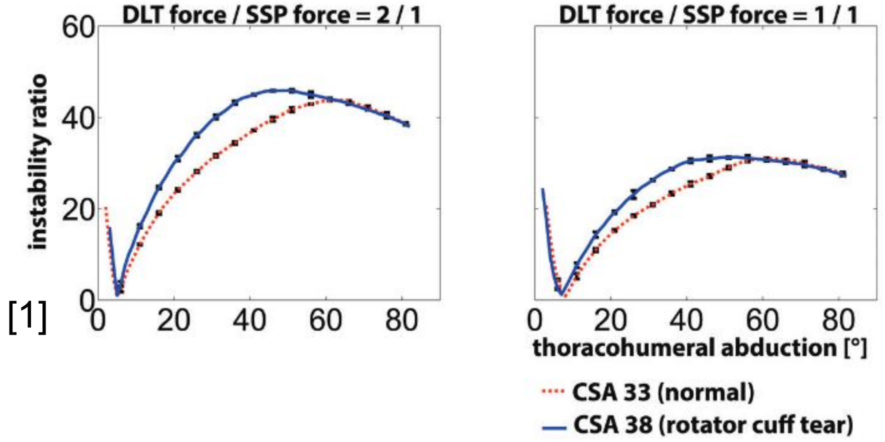
Supraspinatus: abductor in the first degrees of elevation [4]

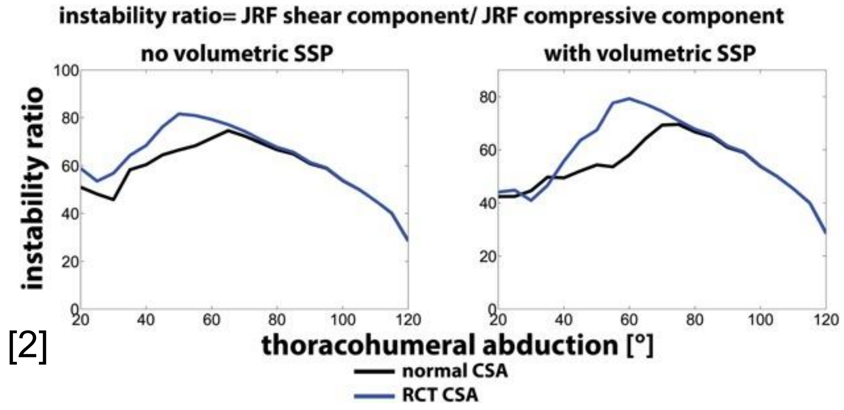
[1] Sharkey et al. (1995)
[2] Halder et al. (2000)
[3] Hawkes et al. (2019)
[4] Reed et al. (2013)

Results | IR sensitivity to acromion length



$$IR = \frac{\sqrt{Fshear_{AP}^2 + Fshear_{IS}^2}}{Fcompression}$$ [1]





[1] Gerber et al. (2014) [2] Viehöfer et al. (2016)

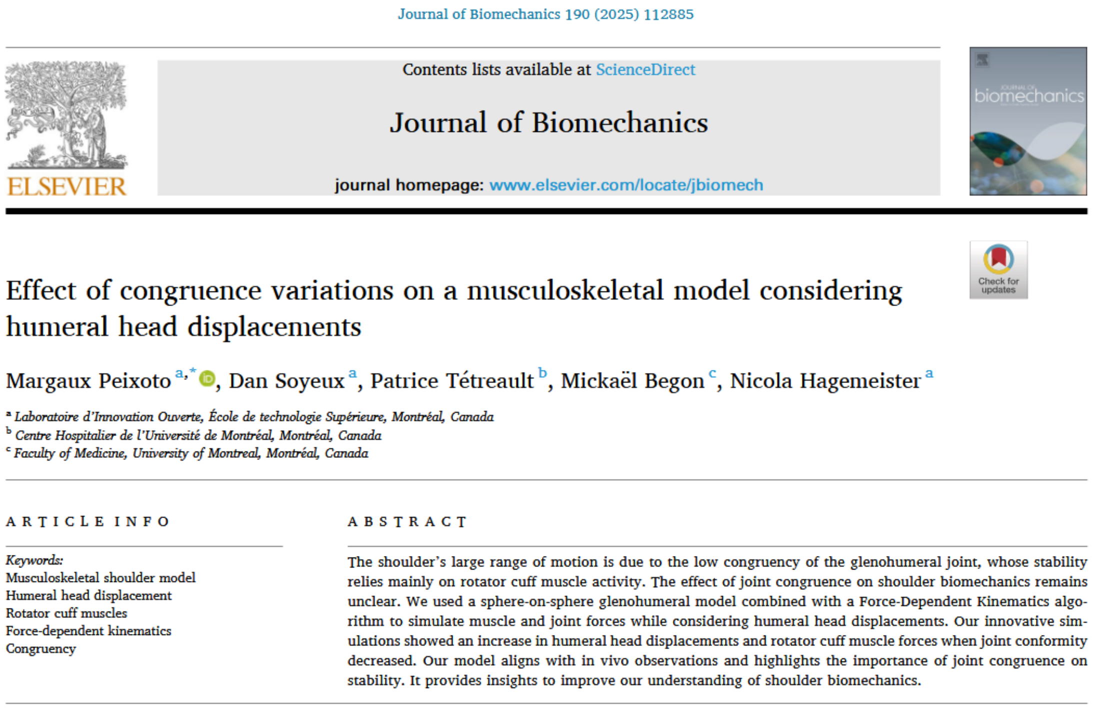
Discussion | Model sensitivity to acromion length

	10 - 60° abduction	60 - 130° abduction	
CSA 28°		**RISK:** Over compression forces [3, 4]	→ **Osteoarthrosis [3]**
↓	• **IR** increases • **Lateral deltoid forces** decrease • **Supraspinatus forces** decrease • **Superior humeral head displacement** increases	• **Lateral deltoid forces** decrease • **Anterior and posterior deltoid, infraspinatus and subscapularis forces** increase	
CSA 38°	**RISK:** Impingement syndrome [1,2]	**RISK:** Overload the rotator cuff muscles [4,5, 6] Joint dislocation [4]	→ **Rotator cuff tear [3]**

[1] Michener et al. (2003)
[2] Ludewig and Cook (2002)
[3] Moor et al. (2013)
[4] Gerber et al. (2014)
[5] Viehöfer et al. (2016)
[6] Hawkes et al. (2019)

Conclusion | Model sensitivity to acromion length

The SoS-FDK model offers a mechanical explanation of the correlations between shoulder pathologies and one clinical parameter on the scapula.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https://github.com/AnyBody/sphere-on-sphere_shoulder_model

Context | Rotator cuff tears

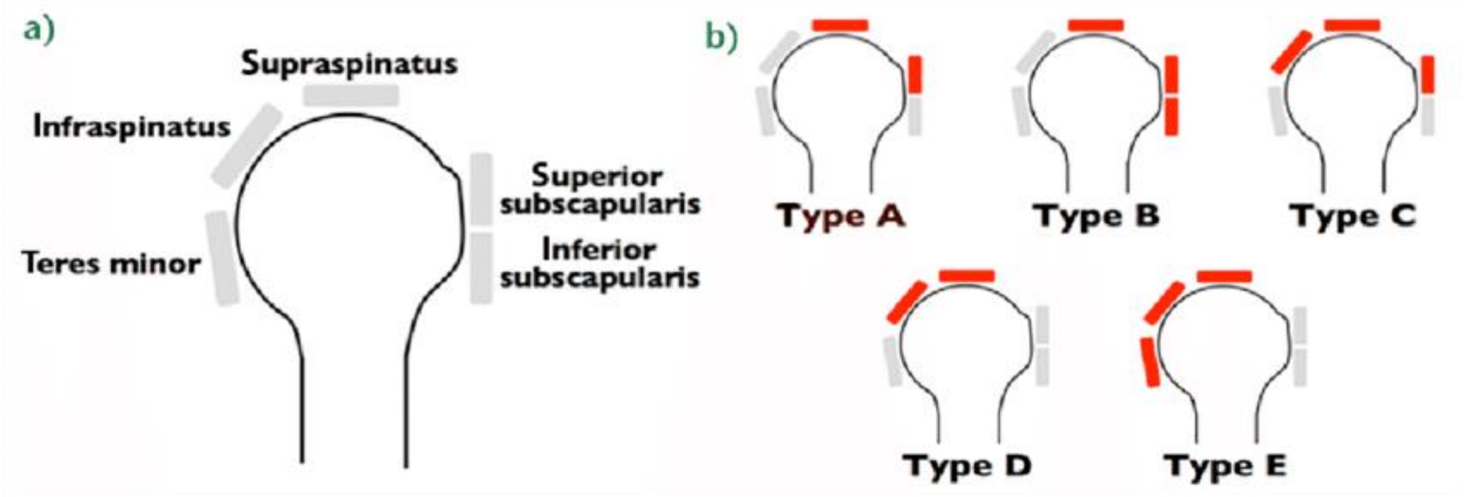
Muscles compensation (in vivo studies, patients with RCTs):

- Lateral deltoid [2]
- Posterior deltoid [2,3]
- Biceps brachii [2,3]
- Teres major [2]
- Latissimus dorsi [2]
- Trapezius [4]
- Subscapularis [2]

- Infraspinatus and supraspinatus activate despite being torn [2,4]

Only few, heterogenies studies:

→ Collin's classification [1]



Collin (2014)

[1] Collin et al. (2014)
[2] Hawkes et al (2012)
[3] Veen et al (2021)
[4] Kelly et al (2005)

2rst research question

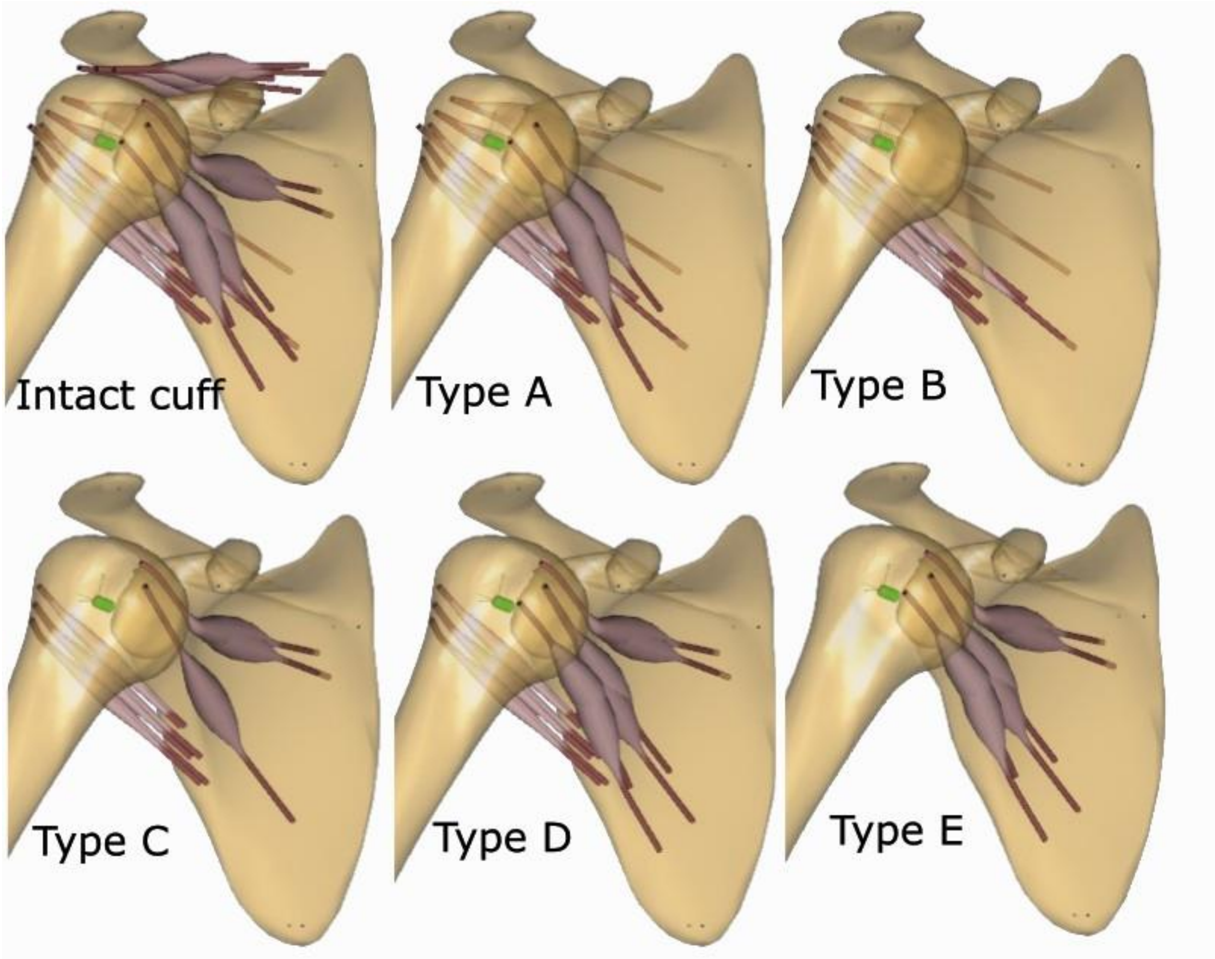
Objectif: *assess the relevant of the SoS-FDK model to study RCTs effect on the glenohumeral joint biomechanics.*

Research question: *"Does the RCT type influence the stability of the glenohumeral joint ?"*

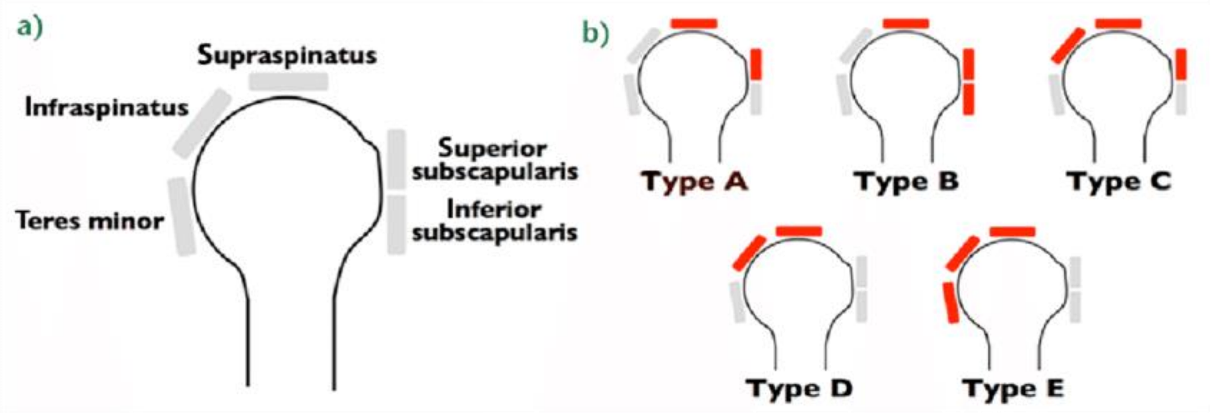
Hypothesis: *muscles with similar lines of action will compensate [1]. Massive RCT (3 muscles torn), will be less stable.*

[1] Ackland et al. (2009)

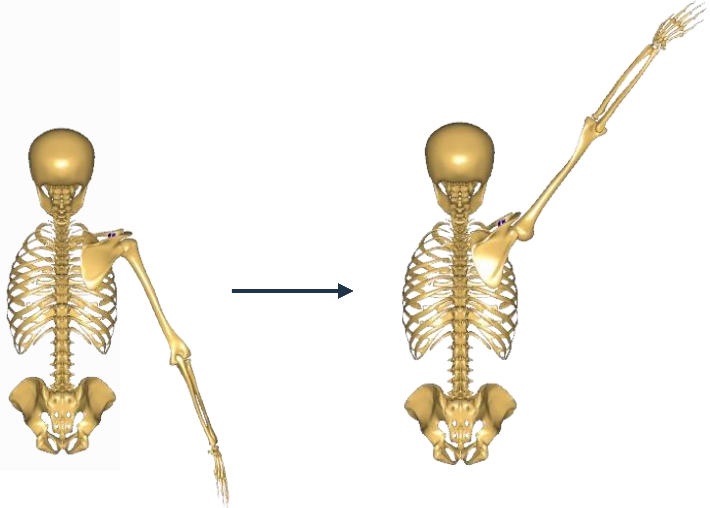
Methods | RCTs simulation (Collin's classification)



muscle torn: max forces = 0N



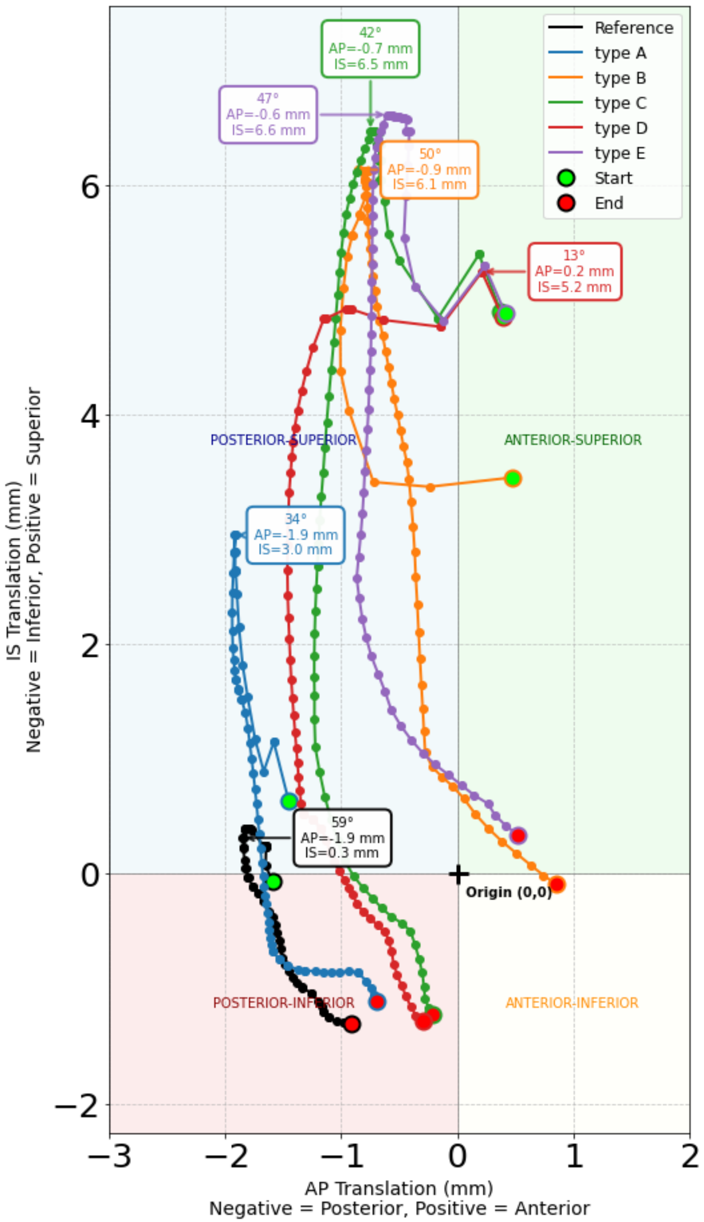
Collin (2014)

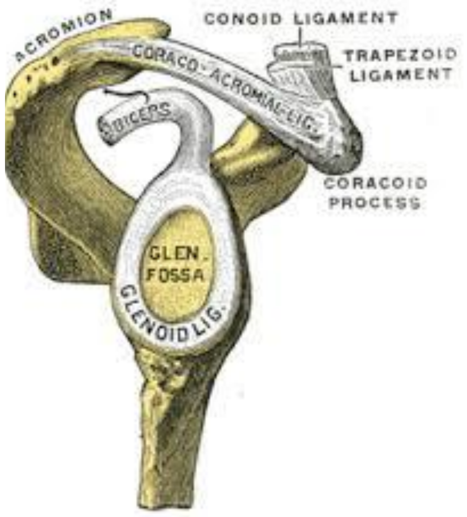


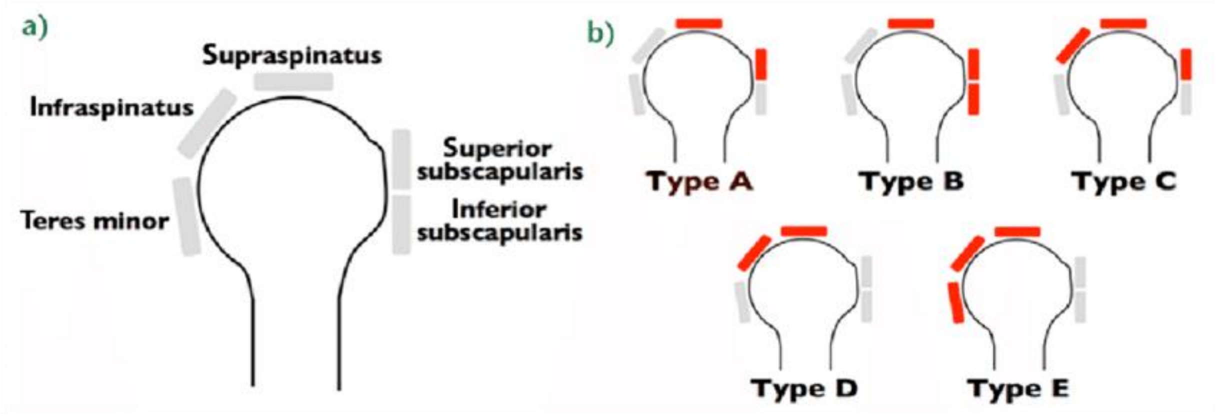
Simulation: Abduction in the scapula plan up to 120 degrees

[1] Collin et al. (2014)

Results | RCTs effect on humeral head translations



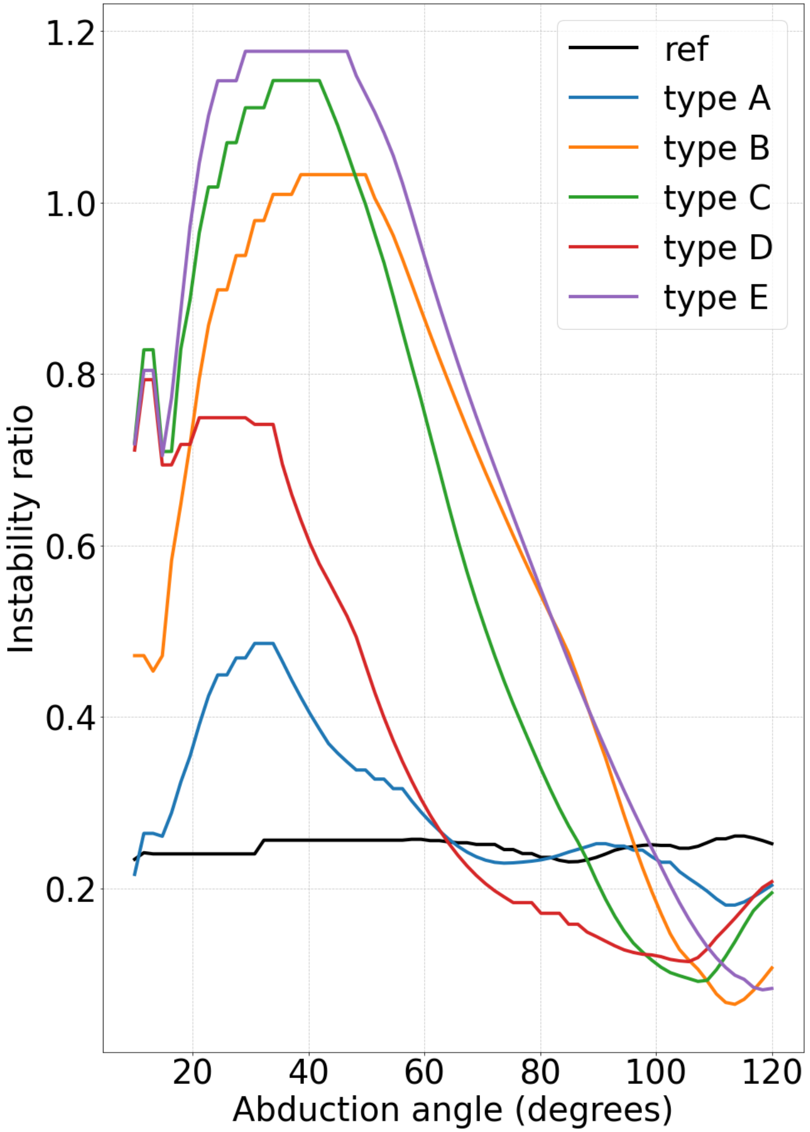


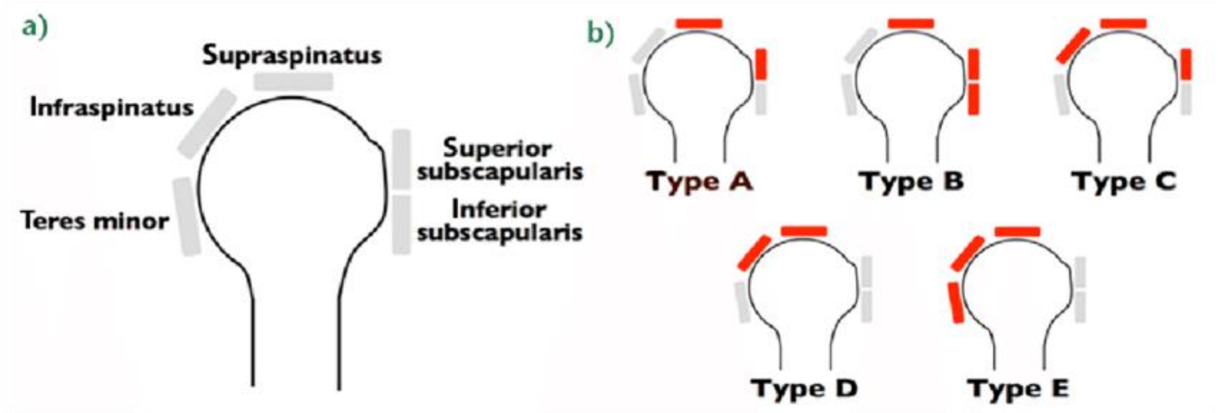


Collin (2014)

- Type A: the closest to intact cuff's kinematic
- Other types: hight superior translation (>6mm for B, C, E)

Results | RCTs effect on instability ratio





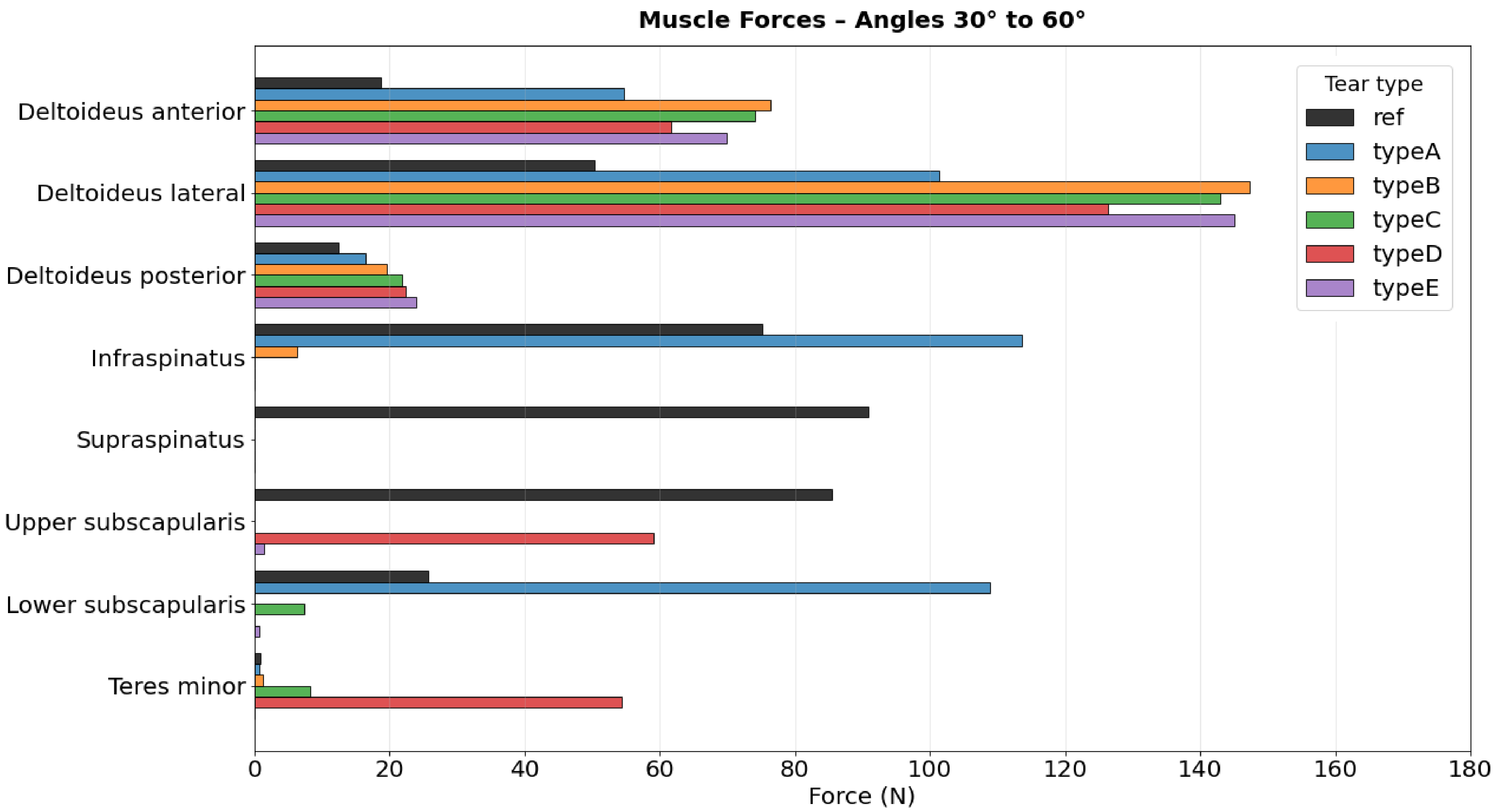
Collin (2014)

$$IR = \frac{\sqrt{Fshear_{AP}^2 + Fshear_{IS}^2}}{Fcompression}$$ [1]

- Type A and D: IR <1
- Type B, C and E: IR >1, risk of dislocation

[1] Gerber et al. (2014)

Results | RCTs effect on muscle forces



Discussion-conclusion | RCTs effect on shoulder biomechanics

- Deltoids activity increase for every tears
- Cuff compensation is tear specific
- Type A is the more stable and have the more efficient compensatory responds
- Larger tear (B, C and E) don’t achieve stability

While deltoid muscles consistently increase force to preserve abduction, compensatory recruitments of remaining cuff and scapular muscles are tear-specific according to Collin et al. (2014)’s classification.

Conclusion | Model sensitivity to RCT types

Understanding the influence and impact of shoulder muscles during a rotator cuff tear according to Collin's classification: a musculoskeletal model study

Currently under review (Journal of Biomechanics)

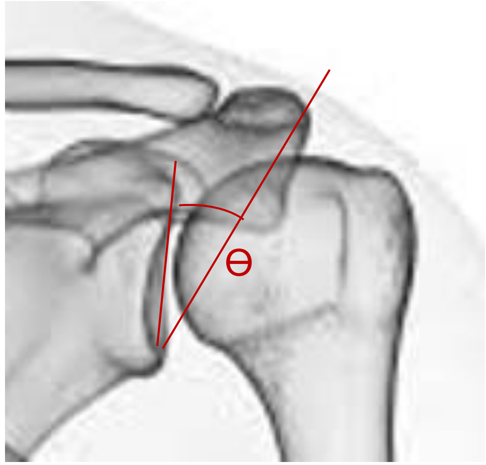
Pre print available:
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5927062

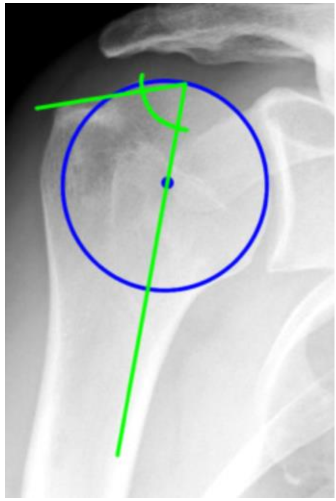
https://github.com/AnyBody/sphere-on-sphere_shoulder_model

Perspectives

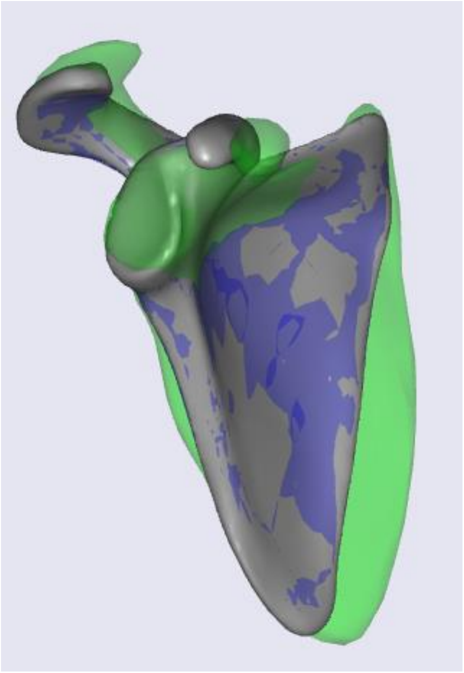
Assess the effect of the scapula and humerus morphology on the shoulder stability in case of RCT.

scapula (Critical Shoulder Angle) [1] + humerus (Greater Tuberosity Angle) [2]



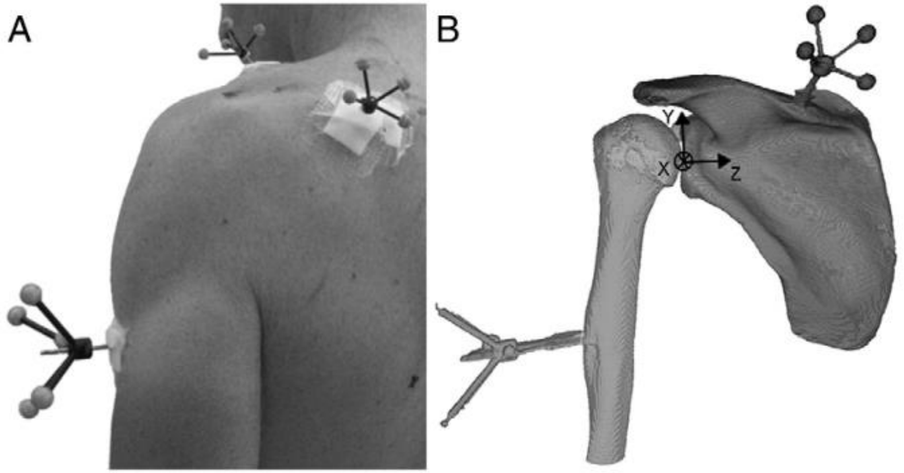


Model personalization: 6 patients

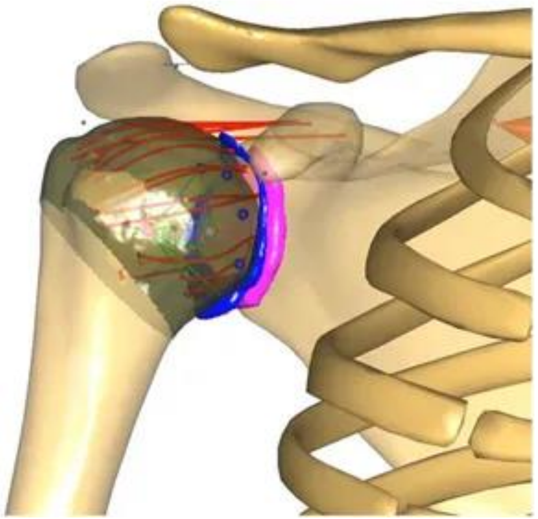


[1] Moor et al. (2013)
[2] Cunningham et al. (2018)

Limits



Validation [1]



Soft tissues representation [2]

Daily life activities

[1] Dal Maso et al. (2014)
[2] Menze et al. (2025)

Thank you

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https://github.com/AnyBody/sphere-on-sphere_shoulder_model

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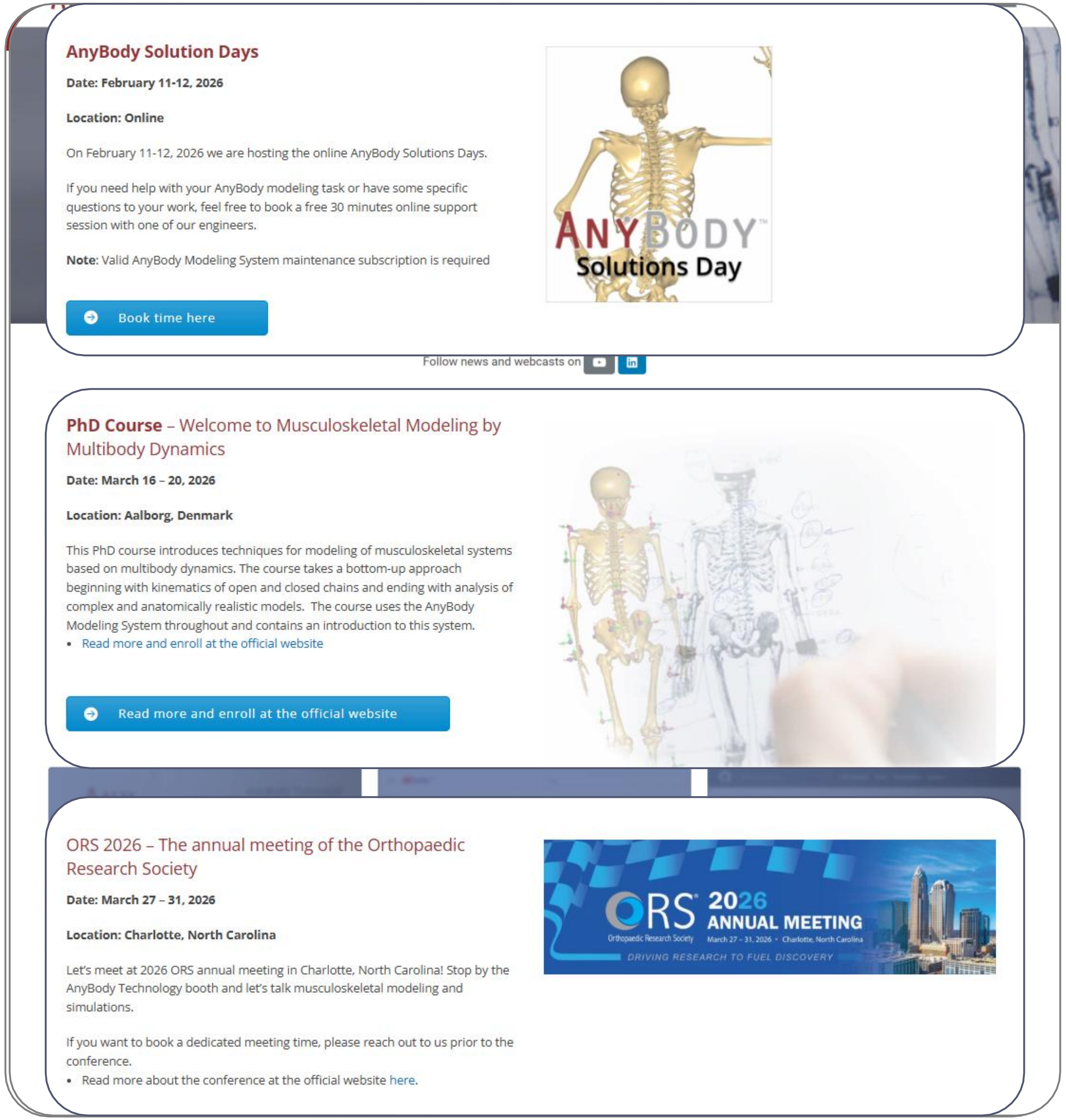
Resources

- **www.anybodytech.com**
  - Events, Webcast library, Publication list, …
- **www.anyscript.org**
  - Wiki, Blog, Repositories, Forum
- **Events**
  - AnyBody Solution Days
    - February 11 – 12, 2026; Online
  - PhD Course: Musculoskeletal Modeling by Multibody Dynamics
    - March 16 – 20, 2026; Aalborg, Denmark
  - ORS 2026 (Orthopaedic Research Society)
    - March 27 – 31, 2026; Charlotte, North Carolina, USA



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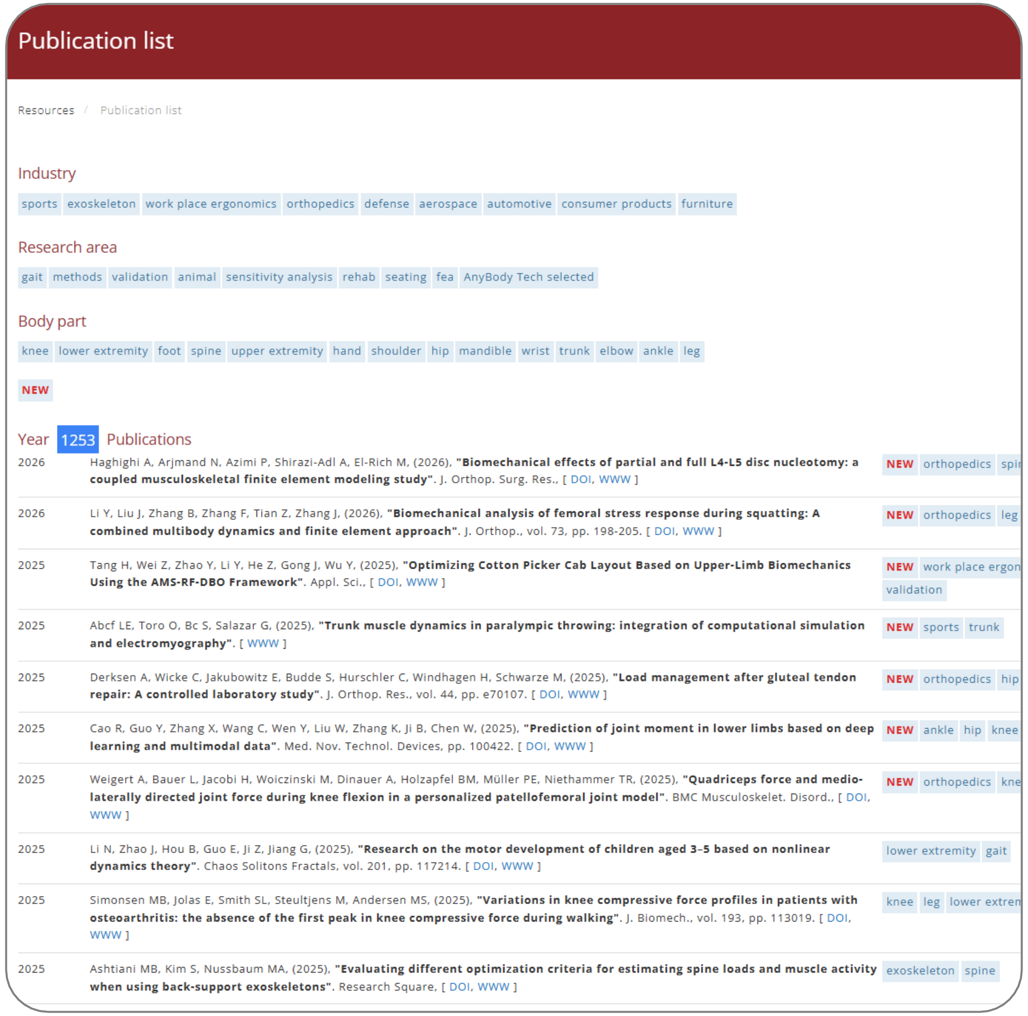

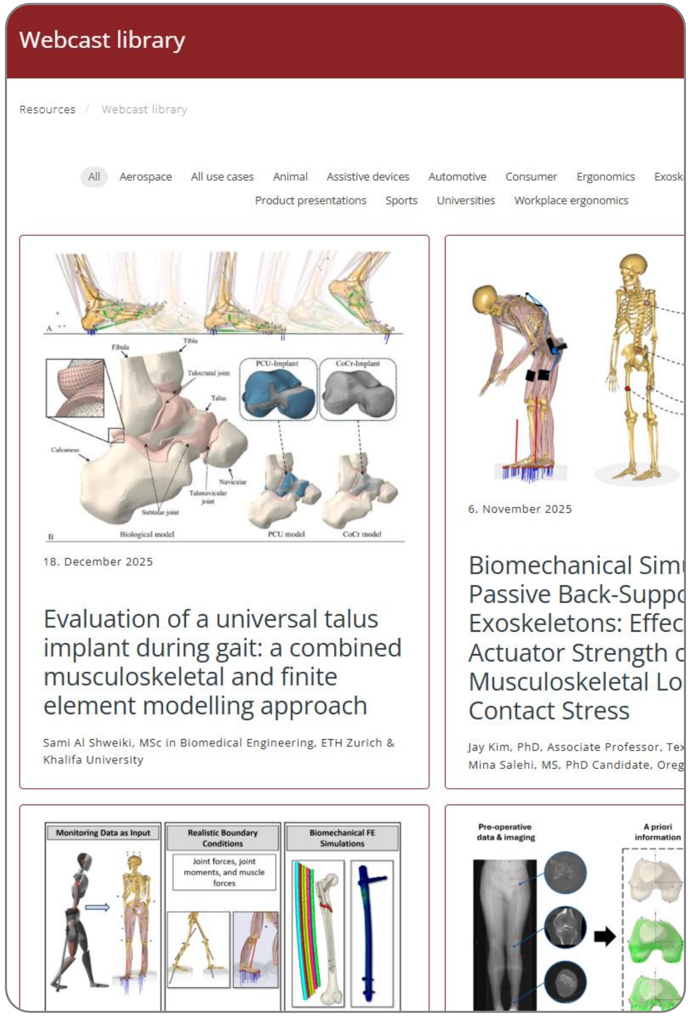

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Thank you for your attention!