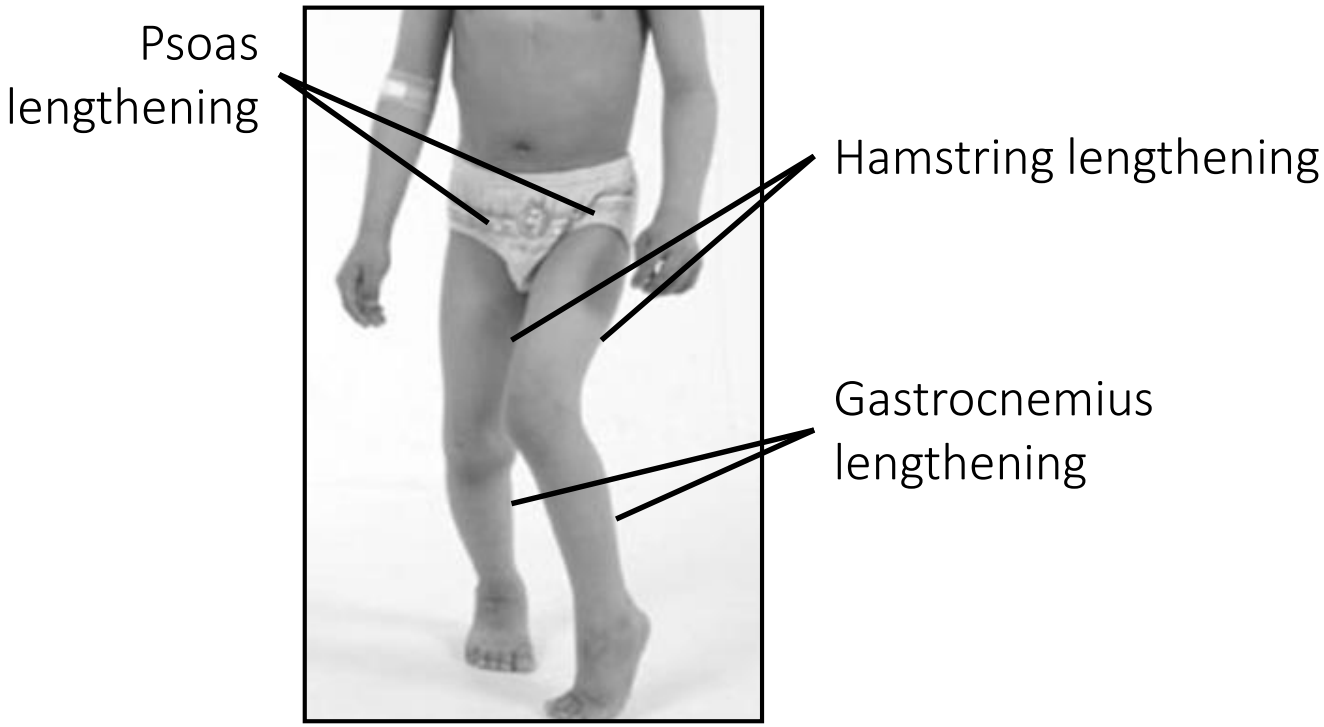
Estimating muscle-tendon length

Hans Kainz

Musculoskeletal modelling to support clinical gait analysis: theoretical, practical, and hands-on considerations

ESMAC 2022 – September 21, 2022

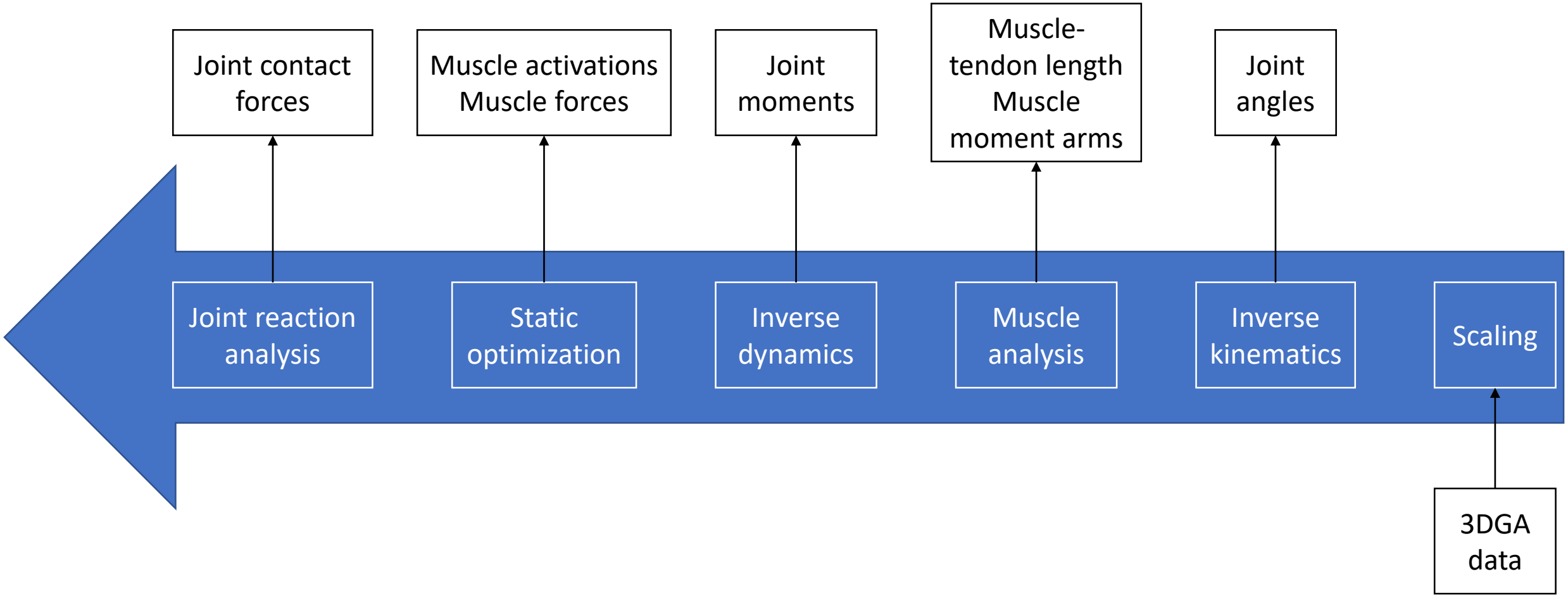
Muscle-tendon length analysis can improve clinical decision-making



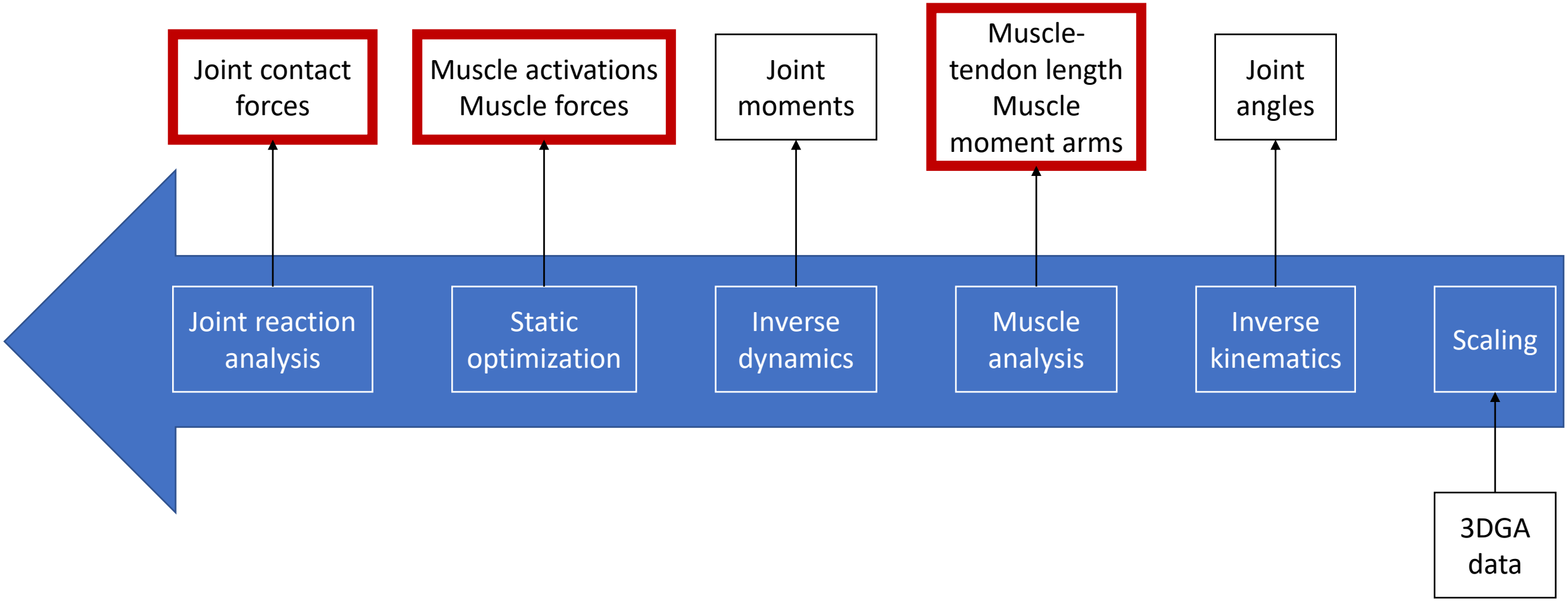
Muscle-tendon lengths are not included as outcome parameter in many gait laboratories.

Rajagopal et al., 2020

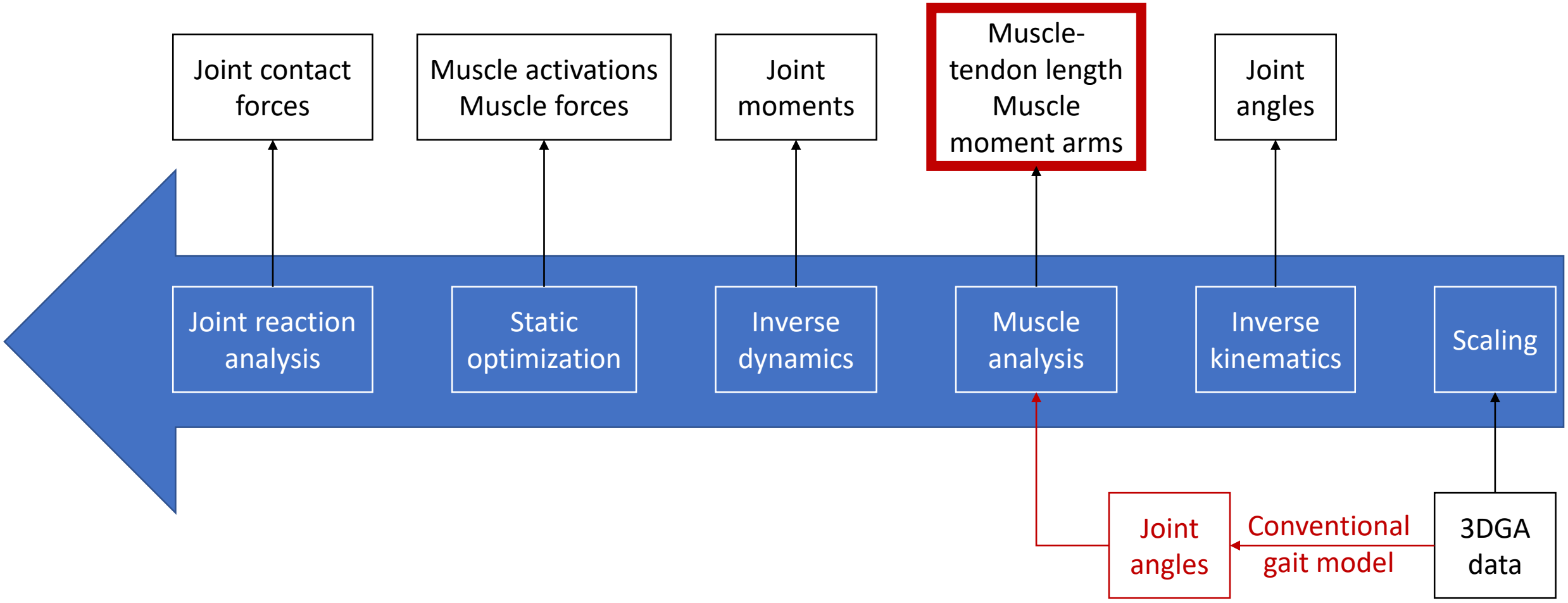
Standard approach to estimate muscle-tendon length



Standard approach to estimate muscle-tendon length

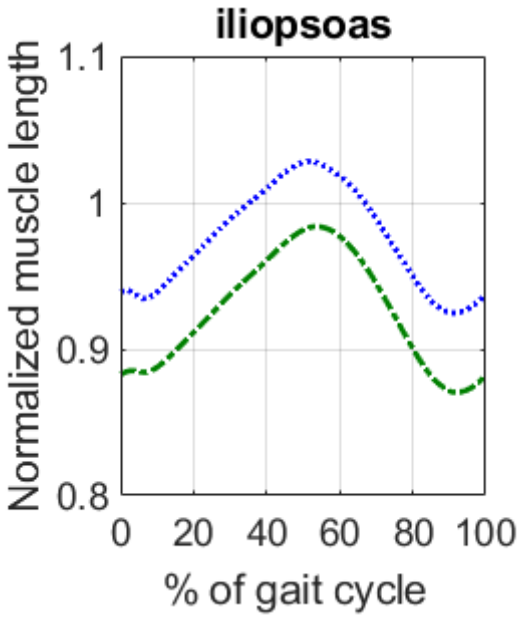


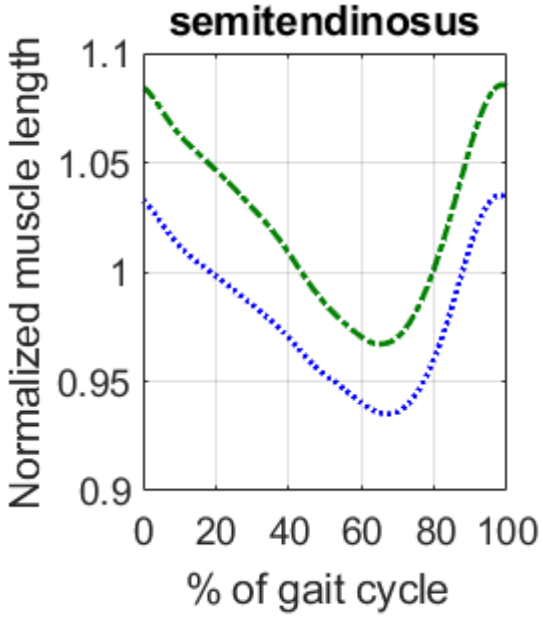
Alternative approach to estimate muscle-tendon length

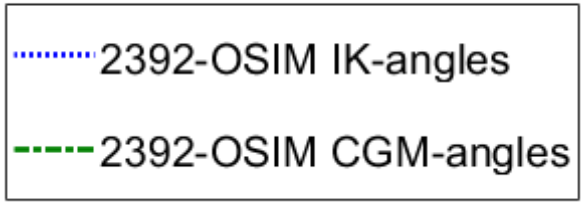


Bar-On et al. 2014
Laracca et al. 2014
Arnold et al. 2006

Different results between approaches







Kainz and Schwartz, 2021

Workflow for consistent results

1. Modify anatomical model
   - Segment frames
   - Joint degrees-of-freedom

2. Create .mot file from your .c3d files

3. Estimate muscle-tendon length with your modified model

Modify segment frame

```
        </Body>
        <Body name="femur_r">
            <mass>9.3014</mass>
            <mass_center> 0 -0.17 0</mass_center>
            <inertia_xx>0.1339</inertia_xx>
            <inertia_yy>0.0351</inertia_yy>
            <inertia_zz>0.1412</inertia_zz>
            <inertia_xy>0</inertia_xy>
            <inertia_xz>0</inertia_xz>
            <inertia_yz>0</inertia_yz>
            <!--Joint that connects this body with the parent body.-->
            <Joint>
                <CustomJoint name="hip_r">
                    <!--Defines how the child body moves with respect to the parent as a function of the
                    <SpatialTransform>
                    <parent_body>pelvis</parent_body>
                    <location_in_parent> -0.0707 -0.0661 0.0835</location_in_parent>
                    <orientation_in_parent> 0 0 0</orientation_in_parent>
                    <location> 0 0 0</location>
                    <orientation> 0 0 0</orientation>
                    <!--Generalized coordinates parameterizing this joint.-->
                    <CoordinateSet>
                        <objects>
                            <Coordinate name="hip_flexion_r">
                                <!--Coordinate can describe rotational, translational, or coupled motion.
                                <motion_type>rotational</motion_type>
                                <!--The value of this coordinate before any value has been set. Rotational
                                <default_value>0</default_value>
                                <!--The speed value of this coordinate before any value has been set. Rota
                                <default_speed_value>0</default_speed_value>
```

```
        <!--Joint that connects this body with the parent body.-->
        <Joint>
            <CustomJoint name="hip_r">
                <!--Defines how the child body moves with respect to the parent as a fu
                <SpatialTransform>
                <parent_body>pelvis</parent_body>
                <location_in_parent> -0.0707 -0.0661 0.0835</location_in_parent>
                <orientation_in_parent> 0 0 -0.226893</orientation_in_parent>
                <location> 0 0 0</location>
                <orientation> 0 0 0</orientation>
                <!--Generalized coordinates parameterizing this joint.-->
                <CoordinateSet>
                    <objects>
```

Modify segment frame

```
<Body name="pelvis">
    <mass>11.777</mass>
    <mass_center> -0.0707 0 0</mass_center>
    <inertia_xx>0.1028</inertia_xx>
    <inertia_yy>0.0871</inertia_yy>
    <inertia_zz>0.0579</inertia_zz>
    <inertia_xy>0</inertia_xy>
    <inertia_xz>0</inertia_xz>
    <inertia_yz>0</inertia_yz>
    <!--Joint that connects this body with the parent body.-->
    <Joint>
        <CustomJoint name="ground_pelvis">
            <!--Defines how the child body moves with respect to the parent as a function of the
            <SpatialTransform>
            <parent_body>ground</parent_body>
            <location_in_parent> 0 0 0</location_in_parent>
            <orientation_in_parent> 0 0 0</orientation_in_parent>
            <location> 0 0 0</location>
            <orientation> 0 0 0</orientation>
            <!--Generalized coordinates parameterizing this joint.-->
            <CoordinateSet>
                <objects>
                    <Coordinate name="pelvis_tilt">
                        <!--Coordinate can describe rotational, translational, or coupled motion.
                        <motion_type>rotational</motion_type>
                        <!--The value of this coordinate before any value has been set. Rotationa
                        <default_value>0</default_value>
                        <!--The speed value of this coordinate before any value has been set. Rot
                        <default_speed_value>0</default_speed_value>
                        <!--The minimum and maximum values that the coordinate can range between.
                        <range>-1.57079633 1.57079633</range>
                        <!--Flag indicating whether or not the values of the coordinates should k
```

```
        <CustomJoint name="ground_pelvis">
            <!--Defines how the child body moves with respect to the parent as a fu
            <SpatialTransform>
            <parent_body>ground</parent_body>
            <location_in_parent> 0 0 0</location_in_parent>
            <orientation_in_parent> 0 0 0</orientation_in_parent>
            <location> 0 0 0</location>
            <orientation> 0 0 -0.226893</orientation>
            <!--Generalized coordinates parameterizing this joint.-->
            <CoordinateSet>
                <objects>
                    <Coordinate name="pelvis_tilt">
                        <!--Coordinate can describe rotational, translational, or c
                        <motion_type>rotational</motion_type>
```

Add joint degree of freedom

```
            <location_in_parent> 0 0 0</location_in_parent>
            <orientation_in_parent> 0 0 0</orientation_in_parent>
            <location> 0 0 0</location>
            <orientation> 0 0 0</orientation>
            <!--Generalized coordinates parameterizing this joint.-->
            <CoordinateSet>
                <objects>
                    <Coordinate name="knee_angle_r">
                        <!--Coordinate can describe rotational, translational, or c
                        <motion_type>rotational</motion_type>
                        <!--The value of this coordinate before any value has been
                        <default_value>0</default_value>
                        <!--The speed value of this coordinate before any value has
                        <default_speed_value>0</default_speed_value>
                        <!--The minimum and maximum values that the coordinate can
                        <range>-2.0943951 0.17453293</range>
                        <!--Flag indicating whether or not the values of the coordi
                        <clamped>false</clamped>
                        <!--Flag indicating whether or not the values of the coordi
                        <locked>false</locked>
                        <!--If specified, the coordinate can be prescribed by a fun
                        <prescribed_function />
                    </Coordinate>
                </objects>
                <groups />
            </CoordinateSet>
            <reverse>false</reverse>
        </CustomJoint>
    </Joint>
    <VisibleObject>
```

```
<CoordinateSet>
    <objects>
        <Coordinate name="knee_angle_r">
            <!--Coordinate can describe rotational, translatio
            <motion_type>rotational</motion_type>
            <!--The value of this coordinate before any value
            <default_value>0</default_value>
            <!--The speed value of this coordinate before any
            <default_speed_value>0</default_speed_value>
            <!--The minimum and maximum values that the coordi
            <range>-2.0943951 0.17453293</range>
            <!--Flag indicating whether or not the values of t
            <clamped>false</clamped>
            <!--Flag indicating whether or not the values of t
            <locked>false</locked>
            <!--If specified, the coordinate can be prescribed
            <prescribed_function />
        </Coordinate>
        <Coordinate name="knee_abduction_r">
            <!--Coordinate can describe rotational, translatio
            <motion_type>rotational</motion_type>
            <!--The value of this coordinate before any value
            <default_value>0</default_value>
            <!--The speed value of this coordinate before any
            <default_speed_value>0</default_speed_value>
            <!--The minimum and maximum values that the coordi
            <range>-2.0943951 2.0943951</range>
            <!--Flag indicating whether or not the values of t
            <clamped>false</clamped>
            <!--Flag indicating whether or not the values of t
            <locked>false</locked>
            <!--If specified, the coordinate can be prescribed
            <prescribed_function />
        </Coordinate>
    </objects>
    <groups />
</CoordinateSet>
```

Add joint degree of freedom

```
<Joint>
    <CustomJoint name="knee_r">
        <!--Defines how the child body moves with respect to the parent as a fu
        <SpatialTransform>
            <!--3 Axes for rotations are listed first.-->
            <TransformAxis name="rotation1">
                <!--Names of the coordinates that serve as the independent vari
                <coordinates>knee_angle_r</coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>0 0 1</axis>
                <!--Transform function of the generalized coordinates used to
                <function>
                    <LinearFunction>
                        <coefficients> 1 0</coefficients>
                    </LinearFunction>
                </function>
            </TransformAxis>
            <TransformAxis name="rotation2">
                <!--Names of the coordinates that serve as the independent vari
                <coordinates></coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>0 1 0</axis>
                <!--Transform function of the generalized coordinates used to
                <function>
                    <Constant>
                        <value>0</value>
                    </Constant>
                </function>
            </TransformAxis>
            <TransformAxis name="rotation3">
                <!--Names of the coordinates that serve as the independent vari
                <coordinates></coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>1 0 0</axis>
                <!--Transform function of the generalized coordinates used to
                <function>
                    <Constant>
                        <value>0</value>
                    </Constant>
                </function>
            </TransformAxis>
            <!--3 Axes for translations are listed next.-->
            <TransformAxis name="translation1">
                <!--Names of the coordinates that serve as the independent vari
                <coordinates>knee_angle_r</coordinates>
                <!--Rotation or translation axis for the transform.-->
```

```
<Joint>
    <CustomJoint name="knee_r">
        <!--Defines how the child body moves with respect to the parent
        <SpatialTransform>
            <!--3 Axes for rotations are listed first.-->
            <TransformAxis name="rotation1">
                <!--Names of the coordinates that serve as the independ
                <coordinates>knee_angle_r</coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>0 0 1</axis>
                <!--Transform function of the generalized coordinates
                <function>
                    <LinearFunction>
                        <coefficients> 1 0</coefficients>
                    </LinearFunction>
                </function>
            </TransformAxis>
            <TransformAxis name="rotation2">
                <!--Names of the coordinates that serve as the independ
                <coordinates></coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>0 1 0</axis>
                <!--Transform function of the generalized coordinates
                <function>
                    <Constant>
                        <value>0</value>
                    </Constant>
                </function>
            </TransformAxis>
            <TransformAxis name="rotation3">
                <!--Names of the coordinates that serve as the independ
                <coordinates>knee_abduction_r</coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>1 0 0</axis>
                <!--Transform function of the generalized coordinates
                <function>
                    <LinearFunction>
                        <coefficients> 1 0</coefficients>
                    </LinearFunction>
                </function>
            </TransformAxis>
            <!--3 Axes for translations are listed next.-->
            <TransformAxis name="translation1">
                <!--Names of the coordinates that serve as the independ
                <coordinates>knee_angle_r</coordinates>
                <!--Rotation or translation axis for the transform.-->
                <axis>1 0 0</axis>
```

Create .mot file from your .c3d files

```
% the .mot file are used to calculate muscle-tendon length in OpenSim
% please cite following paper when using this code:
% Kainz and Schwartz (2021) The importance of a consistent workflow to estimate muscle-tendon lengths based on
% joint angles from the conventional gait model. Gait & Posture.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all; clc; close all;
% add btk folder to path
folder = [pwd '\BTK'];
addpath(genpath(folder));
% define reference OpenSim model
model_ref = 'gait2392_PiGpelvisFrame3DoFkneeNoTorso.osim';
% define relevant angles in OpenSim model for the right leg (change if you use a different model)
angleSet_OpenSim_Model = {'hip_flexion_r' 'hip_adduction_r' 'hip_rotation_r' 'knee_flexion_r' 'knee_adduction_r' 'knee_rotation_r' 'ankle_angle_r' 'subtalar_angle_r'};
% define correspnding angles from c3d file (change is the names are different in your
% files)
angleSet_Clinical_Model = {'RHipAngles' 'RKneeAngles' 'RAnkleAngles'};
% load c3d file
            fileName = 'test.c3d' % change name and path if needed
            dataC3D = btk_loadc3d(fileName);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% get model coordinates from OpenSim reference model
            import org.opensim.modeling.*;
            model = Model(model_ref);
            num = model.getNumCoordinates();
            cordSet= model.getCoordinateSet();
```

Kainz and Schwartz (2021)
https://doi.org/10.1016/j.gaitpost.2021.04.039
https://github.com/HansUniVie/MuscleLength

Estimate muscle-tendon length

- Using the test.mot file (was created with the Matlab script)
- Plot semiten_r muscle length
- Using three different model
  - Generic 2392 model
  - Your modified model
  - gait2392_PiGpelvisFrame3DoFkneeNoTorso.osim model
- Play, e.g. lock degrees-of-freedom, with the model and investigate the impact on your results

Take-home message

- Know your model (and it‘s limitation)
- Consistency, consistency, consistency!

References

- Arnold, A.S., Liu, M.Q., Schwartz, M.H., Õunpuu, S., Delp, S.L., 2006. The role of estimating muscle-tendon lengths and velocities of the hamstrings in the evaluation and treatment of crouch gait. Gait Posture 23, 273–281. https://doi.org/10.1016/j.gaitpost.2005.03.003
- Bar-On, L., Molenaers, G., Aertbeliën, E., Monari, D., Feys, H., Desloovere, K., 2014. The relation between spasticity and muscle behavior during the swing phase of gait in children with cerebral palsy. Res. Dev. Disabil. 35, 3354–3364. https://doi.org/10.1016/j.ridd.2014.07.053
- Kainz, H., Schwartz, M.H., 2021. The importance of a consistent workflow to estimate muscle-tendon lengths based on joint angles from the conventional gait model. Gait Posture 88, 1–9. https://doi.org/10.1016/J.GAITPOST.2021.04.039
- Laracca, E., Stewart, C., Postans, N., Roberts, A., 2014. The effects of surgical lengthening of hamstring muscles in children with cerebral palsy - The consequences of pre-operative muscle length measurement. Gait Posture 39, 847–851. https://doi.org/10.1016/j.gaitpost.2013.11.010
- Rajagopal, A., Kidziński, Ł., McGlaughlin, A.S., Hicks, J.L., Delp, S.L., Schwartz, M.H., 2020. Pre-operative gastrocnemius lengths in gait predict outcomes following gastrocnemius lengthening surgery in children with cerebral palsy. PLoS One 15, e0233706. https://doi.org/10.1371/journal.pone.0233706