Muscles structure and function in children with cerebral palsy

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Agenda

- Clinical picture of Cerebral Palsy
- Treatment of muscle contractures and the implication for gait analysis
- Muscle structure and function
- Muscle modelling
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Cerebral Palsy:

Is defined as a nonprogressive insult to the immature brain, to areas that affect motor function.

Is characterized by motor incoordination that impairs most notably ambulation.

2 of 1000 children are affected [1]

Development over time

• Although the brain lesion is static, the effects on the musculoskeletal system are not

• Spasticity increases the muscle tone

• Soft tissue contractions develop over time

• Without therapeutic intervention the level of ambulation cannot be maintained
Equinus gait
Crouch gait
Hemiplegia unilateral involvement
muscle atrophy in Hemiplegia

Involved, dynamic equinus  healthy
Muscle contracture in Hemiplegia

Involved side fixed equinus
Summary

- Cerebral palsy is a brain damage which cannot be cured and needs lifelong therapy
- Muscle tone is increased by spasticity
- Muscles develop contractures (high muscle stiffness) which reduces ROM and notably affects gait performance
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• Clinical picture of Cerebral Palsy

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• Muscle structure and function

• Muscle modelling
Equinus gait
Instrumented gait analysis

Spatio-temporal parameters

<table>
<thead>
<tr>
<th></th>
<th>left</th>
<th>right</th>
<th>norm</th>
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</thead>
<tbody>
<tr>
<td>step length [cm]</td>
<td>44</td>
<td>52</td>
<td>66</td>
</tr>
<tr>
<td>Geschwindigkeit [km/h]</td>
<td>3,6</td>
<td>4,5</td>
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Power ankle

Generation

Absorption
Relevance of Plantarflexors

- PF generate 40% of the total propulsive work

Sawicki J. Exp. Biol. 2008
Conservative therapies
Orthoses that restrict ankle plantarflexion have good short time effects [1]

8 weeks

Equinus: Therapy outcome after 8 weeks wearing orthoses

Passive Dorsiflexion improved from 10° to 20°

Ankle power at push-off increased
Premature power burst decreased
Surgical procedures, achilles tendon lengthening
Auswirkungen der Ganganalyse auf Operationsentscheidungen

52 - 89 % of descisions based on clinical examination were changed after gait analysis [1-6]

of those 37 - 39 % interventions were cancelled

28 - 40 % were added

Case example

Patient
11 years, bilateral spastic CP, GMFCS II, more involved on the right side, intoeing gait pattern right.

OP Indikation:
suprakondylar Derotation right

Clinical examination:
Hip rotation Int/ext (60/0/30) right
Normal tibial torsion

Question Gait analysis:
How much degrees should the hip be rotated?
Transversal plane joint rotations

Hip rotation within Normal range

Increased tibial torsion right

Foot internal progression right
Decision

+ Foot correction (Evans, NC-Arthrodese)

+ Achilles tendon lengthening (Baumann)

+ supramalleoläre External rotation-Osteotomy (15°).

- Hip rotation not required
Summary

- Plantarflexors generate about 40% of work for propulsion
- Gait analysis helps to identify appropriate Plantarflexor power
- Gait analysis significantly influences surgical decision making
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Introduction

➢ The muscle is a highly adaptive tissue, it responds rapidly to mechanical stress and changes in activity [1].

➢ In hemiplegic patients muscle volume was significantly reduced at the involved leg and biarticular muscles were predominantly affected [2].

Differences in the muscle tendon unit structure in the involved leg have been reported.

It is unknown whether structural changes in the muscle tendon unit are directly related to pathologic function during gait.

**Hypothesis:**
There is a relation between gastrocnemius muscle structure and ankle power production during gait in children with cerebral palsy.
Methods

Patients:
• 12 children and adolescents age 12 (SD=5.2) years 7 females with cerebral palsy (10 diplegia, 2 hemiplegia with involvement in both legs)
• GMFCS I+II (able to walk without walking aids)
• Exclusion: ataxia, athetosis, Botulinum-toxin injections and previous casting of the lower limbs within 6 months as well as any surgical procedures.

Gait analysis:
• Vicon MX Camera system, 2 forceplates
• “Plug-in-Gait” model

Clinical test:
• Passive ankle plantar and dorsiflexion (3 times, knee extended)
• Sonography of gastrocnemius medialis both legs
Methods: sonography

1. Tendon length
   (distance MTJ to heel marker attachment point)

2. Angle of pennation
3. Fascicle length
Method: sonography data evaluation

- Common ROM of all patients was 5 -15° plantarflexion
- 10° plantarflexion was used to determine individual muscle parameters from the regression line
- Lengths were normalized to shank lengths.
Methods: gait data evaluation

1. Push-off energy was determined as the integral of the positive ankle power in late stance phase.

2. Muscle parameters were correlated to the push-off energy for the corresponding leg.
## Predictors of ankle joint energy at push-off

<table>
<thead>
<tr>
<th>Predictor</th>
<th>R</th>
<th>p</th>
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<tbody>
<tr>
<td>angle of pennation [°]</td>
<td>0.03</td>
<td>0.87</td>
</tr>
<tr>
<td>fascicle length [%]</td>
<td>0.26</td>
<td>0.21</td>
</tr>
<tr>
<td>tendon length [%]</td>
<td>-0.58</td>
<td>0.003</td>
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</table>
Predictors graphs

Pearson R = -0.576, p = 0.00319 (normdist 0)

Pearson R = 0.0343, p = 0.874 (normdist)

Pearson R = 0.261, p = 0.217 (normdist 0)
Peak ankle dorsiflexion

pearson R = 0.304 p = 0.149 normdistr 0
Summary results

- The **stronger** legs with greater push-off energy showed **shorter tendons** and **longer fascicles**

- Significant and excellent **correlation of tendon length** with the concentric **push-off energy**
Comparison to other studies

- Longer tendon lengths on the weaker legs
  Corresponds to shorter muscle belly lengths on the more involved side [1,2]

- Shorter fascicle lengths on the weaker legs
  Corresponds to [2,3] but not to [1] showing similar fascicle length

Discussion

- **Longer tendon length** (TL) reduces the muscle belly length, and therefore the muscle volume which might explain a lower push-off force.

- **Shorter fascicle length** (FL) reduces contraction speed and therefore push-off power.

**Interpretation:**
On the weaker side the muscle transformed into a passive force transmitting structure with longer tendon and shorter fascicles aligned along the tendon line of action. This might be useful for passive energy transmission, storage and recoil rather than active force production.
Function of elastic energy

‘storing energy at one stage in the stride and releasing it at another’ Alexander Nature 1977

‘the stored mechanical energy can be used in producing a final velocity greater than that at which the contractile component itself can shorten’ Hill A.V. Proceedings of the Royal Society of London 1950.

Use of elastic energy is important during walking at push-off Ishikawa J. Appl. Physiol. 2005, Hof J. Biomech. 1983

Use of elastic energy of plantarflexors increases gait efficiency about 2.4 times Sawicki J. Exp. Biol. 2009
Discussion

Problem: fascicle length was not correlated with ankle push-off energy!

Possible reason: a passive test was used in this study. The tendon is a passive structure and not that much influenced by the muscle activation such as fascicle length or angle of pennation.
Implications for muscle modelling

Hill-type Muscle Model [1]

Series elastic element length changes the force generation abilities of the contractile element [1-3].

The length should be adapted in simulation models of cerebral palsy patients.

Summary

- Gastrocnemius tendon length correlates with ankle power production
- Longer tendons and shorter fascicles are associated with more impairment during gait
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Human Models in diagnosis and treatment of CP

1. Inverse dynamics models
2. Kinematic models to determine muscle lengths
3. Muscle induced acceleration method
4. Muscle driven forward dynamic simulation
1. Inverse dynamic models

2. Kinematic models to determine muscle lengths

**Application:** Hamstrings in crouch gait: Allison et al. Gait & posture 2006: 273-81

**Further Application:** quantify length changes and effects of body deformities on moment arm (Arnold & Delp J Biomech 2001: 437-47)
2. Muscle induced acceleration method

**Procedure:** forces are applied to single muscle paths and the resulting accelerations in ankle knee and hip joint are analysed (Zajac & Gordon Exerc Sport Sci Rev 1989: 187-230)

**Application:** Muscles can accelerate joints they do not cross, e.g. Soleus “plantarflexion knee extension” couple Kimmel Gait & Posture 2006 211-21.
4. Muscle driven forward simulation models

**Procedure:** Use mathematical optimization to find a solution for the set of muscles that drives the model to follow a specific gait pattern.

**Application:** Simulate surgical procedures. Limitation to overcome is that spastic muscle parameters and activation are not well known.
Summary

• Kinematic models of muscle length calculations are helpful to support clinical decision making

• Continued work is needed to ensure that the results generated by musculoskeletal simulations are accurate and clinically relevant
Recommended literature

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