Clinical Gait Analysis

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casus
Goal setting vs. tools

- problems with specific activities
- >> goal setting at this level
- specific interventions might work
- movement analysis: biomechanics
International Classification of Functions (ICF)

Disease

Function / Anatomy
(Impairments)

Activities
(Disabilities)

Participation
(Handicaps)

External Factors

Personal factors
Complete nested decision scheme

- Disability assessment → Decision → no treatment
- General aim of treatment (disability level) → Movement analysis → Decision → Specific treatment
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Gait and movement analysis in clinical practice of rehabilitation medicine
Goal of walking

- To go from one place to another
- Walking speed, Energy & Safety

HOW?

By repeatedly placing one foot in front of the other
Footsteps

**Stridethread**

\[ \text{Stridethread} = \text{Step}_{\text{Right}} + \text{Step}_{\text{Left}} \]

Right steplength

Left steplength
Footsteps (asymmetric)

Stridlength = Right step + Left step

Right steplength

Left steplength
Measure footsteps

![Image of a person walking on a treadmill with a chart of measurements]

www.gaitrite.com
Goal of walking

\[
\text{Stridlength [m]} \div 120 = \text{Walking speed [m/s]}
\]

\[
\text{Cadence [steps/min]}
\]

3.6 km/h = 1 m/s
Walking speed = stride length * cadence

1.50 x 60 / 120 = .75

1.00 x 90 / 120 = .75
Body length and stride length
What is the optimal stridelpength?

StrideLength = BodyHeight \times 0.008 \times \text{StepRate}

![Graph showing relationship between step rate and stride length](image)
Energy

Statute

Stridewidth

Walking speed

Energy Cost

Cadence
Energy measurements during gait

- (ambulatory) oxygen recording
- one ml O2 / min
  - = 5 cal / min
  - = 20 J/min
Human gait is very efficient...

optimal: $\sim 3.4 \text{ J/kg.m}$
How far can you walk on a pastry?

- Energy cost at optimal speed = 0.8 cal/kg.meter
- Total energy cost = 250 kcal
- Distance = \( \frac{250.000}{(0.8 \times 70)} = 4.5 \text{ km} \)
Metabolic Energy Measurement
casus
One stride lasts from initial foot contact until the next *ipsilateral* initial foot contact.
the gait cycle (2)

normalized time: 0 % - 100 %
Heelstrike & Toe-off
the gait cycle (3)

0%  -- stance --  60%  -swing-

100%
the gait cycle (4)

- RIGHT STANCE
- RIGHT SWING
- LEFT SWING
- LEFT STANCE

-- 50 % --
the gait cycle (5)

- **Right Stance**
- **Right Swing**
- **Left Swing**
- **Left Stance**
- **Right Single Support**
- **Left Single Support**
- **Double Support**
- **Double Support**
- **Double Support**
Functional division of gait phases (after J. Perry)

Stride (gait cycle)

- Stance
  - Weight Acceptance
    - Initial Contact
    - Loading Response
  - Single Limb Support
    - Mid Stance
    - Terminal Stance
- Swing
  - Limb Advancement
    - Pre Swing
    - Mid Swing
    - Initial Swing
    - Terminal Swing
Initial Contact 0 %
Loading Response 0-10 %
Functional division of gait phases
(after J. Perry)

- Stride (gait cycle)
  - Stance
    - Weight Acceptance
      - Initial Contact
    - Single Limb Support
      - Loading Response
      - Mid Stance
      - Terminal Stance
  - Swing
    - Limb Advancement
      - Pre Swing
      - Mid Swing
      - Initial Swing
      - Terminal Swing
Midstance 10 - 30 %
Terminal Stance  30 - 50 %
Functional division of gait phases (after J. Perry)

Stride (gait cycle)

Stance
- Weight Acceptance
  - Initial Contact
  - Loading Response
- Single Limb Support
  - Mid Stance
  - Terminal Stance
- Limb Advancement
  - Pre Swing
  - Mid Swing

Swing
- Initial Swing
- Terminal Swing
Pre-Swing  50 - 60 %
Initial-Swing  60 - 73 %
Functional division of gait phases
(after J. Perry)

Stride (gait cycle)

Stance
- Weight Acceptance
  - Initial Contact
  - Loading Response
- Single Limb Support
  - Mid Stance
  - Terminal Stance
- Limb Advancement
  - Pre Swing
  - Mid Swing
  - Initial Swing
  - Terminal Swing

Swing
Mid-Swing 73 - 87 %
Terminal-Swing 87 - 100 %
Functional division of gait phases
(after J. Perry)

Stride (gait cycle)
- Stance
  - Weight Acceptance
    - Initial Contact
    - Loading Response
  - Single Limb Support
    - Mid Stance
    - Terminal Stance
- Swing
  - Limb Advancement
    - Pre Swing
    - Mid Swing
    - Terminal Swing
    - Initial Swing
The gait cycle

M. Whittle
videorapport loopanalyse

datum opname:   /   /

filenaam STUDY: xxxSYxxx.sty

- rechts
- links

1. initial contact
2. load response
3. midstance
4. terminal stance
5. preswing
6. initial swing
7. midswing
8. terminal swing
Observational Gait Analysis Form
Rancho Los Amigos Medical Centre

<table>
<thead>
<tr>
<th>Reference Limb:</th>
<th>L</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Deviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor Deviation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Weight Accept
- IC
- LR
- MSt
- TSt
- PSw
- ISw
- MSw
- TSw

### Single Limb Support
- Hip: Flexion: Limited
- Excess
- Inadequate Extension
- Past Retract
- Rotation: IR/ER
- AD/ABduction: Ad/Ab
- Knee: Flexion: Limited
- Excess
- Inadequate Extension
- Wobbles
- Hyperextend
- Extension Thrust
- Varus/Valgus: Vr/Vl
- Excess Contralateral Flex
- Ankle: Forefoot Contact
- Foot Flat Contact
- Foot Slap
- Excess Plantar Flexion
- Excess DorsiFlexion
- Inversion/Eversion: h/Ev
- Heel Off
- No Heel Off
- Drag
- Contralateral Vaulting
- Toes: Up
- Inadequate Extension
- Clawed

### Swing Limb Advancement
- Major Problems
- Weight Acceptance
- Single Limb Support
- Swing Limb Advancement

### Excessive UE Weight Bearing
- Name: 
- Patient #: 
- Diagnosis: 

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VU University Medical Center
# Edinburgh GAIT Scoring Table

<table>
<thead>
<tr>
<th>Movement SAGITTAL</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Movement CORONAL/TRANSV</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOOT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FOOT</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1 Foot clearance</td>
<td>None</td>
<td>Reduced</td>
<td>Full</td>
<td>N/A</td>
<td>N/A</td>
<td>5 Stance position hindfoot in load</td>
<td>&gt;5</td>
<td>15</td>
<td>Var</td>
<td>6-15</td>
<td>Var</td>
</tr>
<tr>
<td>2 Initial Contact</td>
<td>Toe</td>
<td>Flatfoot</td>
<td>Heel</td>
<td>N/A</td>
<td>N/A</td>
<td>6 Foot progression angle</td>
<td>&gt;15</td>
<td>IR</td>
<td>6-15</td>
<td>IR</td>
<td>5-0-5</td>
</tr>
<tr>
<td>3 Heel lift</td>
<td>None</td>
<td>Early</td>
<td>Normal</td>
<td>Delayed</td>
<td>N/A</td>
<td></td>
<td></td>
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<tr>
<td>4 Max dorsiflexion hindfoot in stance</td>
<td>&gt;10</td>
<td>Planter</td>
<td>10-0-9</td>
<td>Plan/Dorsif</td>
<td>10-20</td>
<td>Dorsif</td>
<td>21-30</td>
<td>Dorsif</td>
<td>&gt;30</td>
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</tr>
<tr>
<td>KNEE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KNEE</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7 Terminal swing</td>
<td>&gt;30</td>
<td>Flexion</td>
<td>15-30</td>
<td>Flexion</td>
<td>0-15</td>
<td>Flexion</td>
<td>&gt;0</td>
<td>Hypext</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Peak stance knee ext</td>
<td>&gt;30</td>
<td>Flexion</td>
<td>15-30</td>
<td>Flexion</td>
<td>0-15</td>
<td>Flexion</td>
<td>1-10</td>
<td>Hypext</td>
<td>&gt;10</td>
<td>Hypext</td>
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<tr>
<td>9 Peak knee flex in swing</td>
<td>&gt;90</td>
<td>Flexion</td>
<td>65-80</td>
<td>Flexion</td>
<td>60-64</td>
<td>Flexion</td>
<td>60-59</td>
<td>Flexion</td>
<td>&gt;30</td>
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</tr>
<tr>
<td>HIP</td>
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<td>HIP</td>
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</tr>
<tr>
<td>11 Peak hip ext in stance</td>
<td>&gt;30</td>
<td>Flexion</td>
<td>15-30</td>
<td>Flexion</td>
<td>15-6-15</td>
<td>Flexion</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>N/A</td>
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<tr>
<td>12 Peak hip flex in swing</td>
<td>&gt;75</td>
<td>Flexion</td>
<td>51-75</td>
<td>Flexion</td>
<td>30-60</td>
<td>Flexion</td>
<td>15-29</td>
<td>Flexion</td>
<td>&lt;15</td>
<td>Flexion</td>
<td></td>
</tr>
<tr>
<td>PELVIS (Trans)</td>
<td></td>
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<td>PELVIS</td>
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<td></td>
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</tr>
<tr>
<td>14 Pelvic rotation in midstance</td>
<td>&gt;15</td>
<td>Fwd</td>
<td>6-15</td>
<td>Fwd</td>
<td>5-0-5</td>
<td>Neutral</td>
<td>6-15</td>
<td>Bwd</td>
<td>&gt;15</td>
<td>Bwd</td>
<td>15 Contralateral drop in stance</td>
</tr>
<tr>
<td>TRUNK</td>
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<td></td>
<td>TRUNK</td>
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</tr>
<tr>
<td>16 Peak sagittal position in stance</td>
<td>&gt;15</td>
<td>Fwd</td>
<td>6-15</td>
<td>Fwd</td>
<td>5-0-5</td>
<td>Neutral</td>
<td>&gt;6</td>
<td>Bwd</td>
<td></td>
<td></td>
<td>17 Maximal lat shift in stance</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
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<td></td>
<td>TOTAL</td>
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</tr>
</tbody>
</table>

**Note:** IR = Internal Rotation, ER = External Rotation, Cap = Caput, Bwd = Backwards, Fwd = Forward, Mod = Moderate, Var = Varus, N/A = Not Applicable
Error sources in observational kinematic analysis

- Subjective
- estimation error
- out of plane (2D vs. 3D)
Estimation of joint angles

How well do we perform?

148°  24°
Estimation of joint angles

How well do we perform?

148 ° 24 °
Projection error
Projection error
Projection error (2)
Earliest 3D movement analysis
Braun & Fischer 1895
Multiple 2D projections
Calibrate the projection

calibration frame

15 points are known in the real (3D) world

Videobased systems: SYBAR, SIMI, PEAK, . . . .
Automated marker tracking and 3D reconstruction of marker position

Multiple (2+) stroboscopic InfraRed camera's using reflective markers on the body

Vicon, MotionAnalysis, Elite, Qualysis, . . .
Automated marker tracking and 3D reconstruction of marker position (2)

CODAmotion, OptoTrak, . . .
Marker recording → Segment identification → Kinematics

Marker-cluster 1 → Kinematics anatomical segm. #1

Marker-cluster n → Kinematics anatomical segm. #2

Body model → Anatomical reference → Clinical convention → Joint-kinematics
3D Kinematics software

Matlab

www.bodymech.nl
Clinical Feasibility
Clinical Feasibility
Clinical Feasibility
INFORMATION

? = KNOWLEDGE
Observational analysis of pathological movement
Muscle function during movement

Reprinted from: Inman et al. (1981)
Electro Myo Gram (EMG)

EMG is the summation of many asynchronous Motor Unit Action Potentials

Electrode mounted amplifier
differential lead-off
Relation EMG and Muscle Force

- Raw EMG
- Smoothed Rectified EMG @ 2 Hz
- Isometric muscle force
the SYBAR system

recording
the SYBAR system

display
casus
Ground reaction force
Net joint moment

Moment = \( F \times r \)
Estimated net joint moment versus inverse dynamics

Moment = $F \times r$

Boccardi et al. (1981)
What therapeutic intervention is needed?
Evaluation of treatment at two (nested) levels

General aim of treatment (disability level)

- increased walking speed, decreased PCI
- decreased ankle moment at heelstrike

Specific treatment

function analysis

Decision

Decision

no treatment

Disability assessment
What therapeutic intervention is needed?
Complex Clinical Cases
Inverse dynamics model

**Antropometrics:**
- mass
- inertal moments
- joint locations
- muscle attachments

**Dynamics**
- external moments and forces

**Kinematics**
- positions
- angles
- derivatives

**Joint and muscle function**
- net moments
- estimated muscle forces
Problem statement

Physical examination yields angles

The measure should address muscle length

The reference values are based on normal gait
Method

• Application of a geometrical musculo-skeletal model SIMM (Delp et. al 1995)
  • input 1: joint angles during physical examination
  • input 2: joint angles during normal gait
  • output: muscle length (origo-insertion)
  • all lengths are normalized to anatomical position (=100 % )
Results: m. Rectus Femoris (1)
Results: m. Rectus Femoris (2)
Length m. Rectus Femoris during gait
Results: m. Rectus Femoris (3)

![Graph showing percentage changes in gait from stance to swing]
Discussion

• “Passive” muscle length is not the sole cause to contractures during gait
• Muscle length during movement and EMG should be considered
• Warning: validity of the model
• Documentation of examination protocols (standardisation) using modeling software animations creates awareness of muscle length testing
Imaging

• Clinical question
  • visualization
  • muscle-bone model
    • (invers)
  • structure

• load

• (intended) therapeutical intervention

• Functional analysis
  • function
  • muscle-bone model
    • (forward)
  • movement
Models (1)
Pneumatic passive-based biped

Martijn Wisse
Jan van Frankenhuyzen
2004

Delft Biorobotics Laboratory
functional load and loading capability of the upper extremity
Upper extremity
Upper extremity (2)