Introduction

- Goal of workshop
  - Broad overview of many aspects of strength measurement
  - Summarizing current ‘state of the art’
  - Provide relevant background to:
    - Decide on which instruments to use in which patients
    - Decide on the optimal measurement protocol
    - Understand the outcome

Program overview

- General introduction
- Remember your biomechanics?
- Manual muscle testing
- Hand strength dynamometers
- What to measure?
- The Rotterdam Intrinsic Hand Myometer
- Analysis of data
- Case studies: which instruments to use?
- End

The biomechanics or strength measurement

Force, moment arm and moment

\[ \text{Moment} = \text{Force} \times \text{moment arm} \]
Moment arm depends on the joint angle

Muscle strength depend on muscle length and movement

Based on biomechanics, you need to:

- Measure torque or standardize moment arm
- Control the position of the subject
- Control the type of contraction (concentric, isometric, eccentric)
- Other aspects to standardize:
  - instruction of subjects
  - Encouragement
  - Visual feedback

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Manual Muscle Strength Test

Numerical system of grading muscle action

Mitchell (1872) civil war - injuries
Lovett (1916) polio
Lowman (1927)

The Oxford/ British Medical Research Council (MRC) 0 to 5 scale

Medical Research Council. Aids to the investigation of peripheral nerve injuries. 2nd ed. London: Her Majesty’s Stationery Office (1943)

<table>
<thead>
<tr>
<th>Medical Research Council Grades</th>
<th>Movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No contraction</td>
</tr>
<tr>
<td>1</td>
<td>Fiber or trace of contraction</td>
</tr>
<tr>
<td>2</td>
<td>Active movement with gravity eliminated</td>
</tr>
<tr>
<td>3</td>
<td>Active movement against gravity</td>
</tr>
<tr>
<td>4</td>
<td>Active movement against gravity and resistance</td>
</tr>
<tr>
<td>5</td>
<td>Normal power</td>
</tr>
</tbody>
</table>

MRC Scale:
The gravity factor....
**Manual Muscle Strength Test**

Medical Research Council (MRC) 0 to 5 scale

Modification for the Hand: gravity is not taken into consideration

<table>
<thead>
<tr>
<th>Grade</th>
<th>Range of Movement</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>4</td>
<td>Normal</td>
<td>Reduced</td>
</tr>
<tr>
<td>3</td>
<td>Normal</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Reduced</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>None</td>
<td>Palpable contraction only</td>
</tr>
<tr>
<td>0</td>
<td>None</td>
<td>No palpable contraction</td>
</tr>
</tbody>
</table>

Brandsma JW et al, J Hand Ther (1995)

---

**Testing Muscles or Movements?**

- Abductor digiti minimi or Abduction of little finger?
- First dorsal interosseous or Abduction of index finger?
- Abductor Pollicis Brevis or Abduction of thumb?
- Opponens Pollicis or Opposition of thumb?
- Lumbricals/interossei or Intrinsic position?

---

**Limitation 1**

Muscle OR Movement

Textbooks: muscle tests as if muscles tested in isolation. However: usually a muscle group is tested.

- e.g. grading the palmar abduction movement of the thumb instead of m. abductor pollicis brevis (APB)
- Some muscles can be graded in isolation: e.g. FPL, FDP and 1DI.

---

**Limitation 2**

Scale

- 0-5 scale: a constant distance between points
- MRC 0-5 scale = ordinal scale: disproportional distances between grades

NOT: grade 4 is not twice as strong as grade 2
MRC mean muscle strength

---

**Manual Muscle Strength Testing**

versus dynamometry

<table>
<thead>
<tr>
<th>0%</th>
<th>123</th>
<th>4</th>
<th>&gt;5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>Trace</td>
<td>Poor</td>
<td>Fair</td>
</tr>
</tbody>
</table>

RIHM
Manual Muscle Strength Test

Reliability

- Depends on experience of tester
- MRC 0-5 scale (Brandsma et al. J Hand Ther 1995)
  ICCs high: good reliability
- Many modifications of 0-5 scale
  e.g. 9-point scale (Brandsma et al. Lepr Rev 1998)
  grades: 5, 4+, 4, 3+, 3, 2+, 2, 1 and 0
  reliability?

<table>
<thead>
<tr>
<th>Category</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>2+</th>
<th>3</th>
<th>3+</th>
<th>4</th>
<th>4+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
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<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>5</td>
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<td>3</td>
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<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>9</td>
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<tr>
<td></td>
<td>3</td>
<td>1</td>
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<td>2</td>
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<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td></td>
<td></td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>4</td>
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<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>10</td>
<td>55</td>
<td>5</td>
<td>9</td>
<td>14</td>
<td>20</td>
<td>1</td>
<td>129</td>
</tr>
</tbody>
</table>

Agreement matrix (B-C)
Abduction digit 5
Agreement 39.7%
Kw = 0.84

Omitting 0 and 5
Agreement 17.4%
Kw = 0.62

More on reliability

Abd. 5: Little finger abd.
Abd. 2: Index abd.
Abd. 1: Thumb abd.

Kappa scale
< 20 poor
0.21 - 0.40 fair
0.41 - 0.60 moderate
0.61 – 0.80 good
0.81 – 1.00 very good

Abductor Pollicis Brevis (APB)
- action of APB – movement = palmar abduction (anteposition)
- palpate: next to metacarpal bone
- synergist: Opponens Pollicis & Flexor Pollicis Brevis
- place press MCP joint thumb
  parallel with the nail

Abductor Pollicis Longus
- place press MCP joint thumb
  parallel with the nail

Palmar Abduction of thumb
APB + OpP + PPB

Techniques

Abductor Pollicis Brevis (APB)
What action of APB - movement?
Where palpate?
What are synergist?
What place/direction press?

• control wrist (extension) (APL)
• position the thumb in palmar abduction
• ask patient to hold the thumb
• if can: pressure - if not: MRC <3
• pressure at MCP joint
• direction = parallel with the nail
**First Dorsal Interosseous**

**What action?**
- Radial abduction index finger
- Dorsal thumb web

**Where palpate**
- No synergists
- PIP joint index

**What place/direction press?**
- Hand in pronation
- Position the index finger in abduction
- Slight flexion MCP
- Ask patient to hold the finger
- If can: give pressure; if not: MRC <3
- Press at MCP of index
- Direction = plane of hand

**Option**

More functional test in intrinsic plus position

**First Dorsal Interosseous weakness**

**Patients complaints:**
- Holding large objects
- Weak pinch

**Testing Adductor Pollicis (AP)**

- Not possible because of synergists
- Indirect test: check for Froment sign test “+” or “-” based on IP flexion thumb

**Better:**
- Use pinch dynamometer for measurement of AP

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Manual muscle testing versus dynamometry

Grip strength

- Jamar and Vigori dynamometers most often used
- Jamar has repeatedly been found to be more reliable, in adults and in children (direct comparison in Children: Molenaar, Am JBJS, 2008)

Recommendation American Society for Hand Therapy

- Use a Jamar that is calibrated (hydraulic versus electronic)
- Standardized:
  - Position
  - Instruction and verbal support
  - Grip size
  - Calculation (mean of 3)
- Support the Jamar to reduce weight
- Preferable compare to contra-lateral side or pre-operative condition

Pinch strength

- No ASHT recommendations
- Tip pinch
  - Wrist in pronation and extension
  - Dig 3-5 in flexion
- Key pinch or lateral pinch
  - Wrist in neutral
  - Thumb versus mid-phalanx

Wrist flexion and extension

- MicroFET universal manual dynamometer
- Well suited for elbow and wrist

Intrinsic muscle strength dynamometry measurements
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What can you measure?
- Maximum strength (maximum voluntary contraction)
- Fatigue/endurance
- Force coordination
- Detecting malingering / sincerity of effort?
- Dynamometers in children

Maximum strength
- Mostly used: mean of 3 MVC’s with removal of outliers
- Mean of 3 more reliable than maximum of 3
- In some software, outliers are automatically detected (e.g., Eval, E-link)

Fatigue
- Defined as a state with reduced capacity for work following a period of physical activity (Schwid, J Rehabil Res Dev 2002)
- Measured as:
  - Decrease in force during a sustained contraction (e.g., Schwid J Rehabil Res Dev 2002)
  - Decrease in force during repeated maximal contractions (e.g., Videler 2002)
  - …..

Example: fatigue in control subject versus MS patient

Calculating fatigue
Fatigue Index = $\frac{A}{A+B}$
Reliability of fatigue measurements based on sustained or repeated contractions poor to moderate (e.g., Schwid, Neurology, 1999)

Schwid, J Rehabil Res Dev, 2002
Schwid 1999
Force coordination

- The ability to control your strength

Healthy subject

CP patient

Van Meeteren, J Rehab Med, 2007

Detecting malingering

- Many studies have tried to develop technique to detect ‘sincerity of effort’ to detect malingering or disability exaggeration

- Based on the assumption that sub-maximal efforts are more variable than maximal efforts.

- Protocols, for example:
  - Rapid exchange test (e.g., Ghori, Am J Hand Surgery, 2007)

How good can you detect malingering

- On a group level, malingering increases the variation between measurement

- However, sensitivity and specificity are very poor

- Recent review:
  - On a individual level, present techniques are ‘unacceptable from both a clinical and a medico-legal standpoint’ (Shechtman, 2002)

What is different when measuring children?

- Shorter attention span
- Possible lack of task understanding
- Instruments often not developed for children
- Influence of age on reliability

Influence of age on reliability

- Absolute measurement error for the Jamar is similar for each age-group (age 4-12)
- However, relative measurement error is much larger in weaker children!!!

How to approach hand strength measurements children?

- Different protocols to improve reliability & outcome
  - e.g. Using visual feedback or weight reduction of the instrument
Reliability of Jamar dynamometer protocols (n=104)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>ICC</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant</td>
<td>0.96</td>
<td>128</td>
</tr>
<tr>
<td>Non dominant</td>
<td>0.95</td>
<td>119</td>
</tr>
<tr>
<td>Visual Feedback</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant</td>
<td>0.97</td>
<td>129</td>
</tr>
<tr>
<td>Non dominant</td>
<td>0.96</td>
<td>125</td>
</tr>
<tr>
<td>Suspension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant</td>
<td>0.96</td>
<td>140</td>
</tr>
<tr>
<td>Non dominant</td>
<td>0.96</td>
<td>132</td>
</tr>
</tbody>
</table>

No significant differences in reliability between protocols. Output highest in suspension.

(H.M. Molenaar et al., submitted, 2008)

Present research

- Growth-diagrams for grip strength in children
- Easy to monitor a child’s development at follow-up.

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Dynamometry of intrinsic muscles necessary?

Several patients good grip strength but poor intrinsic muscle strength—grip strength measurements appropriate to assess intrinsics??

Dynamometry of intrinsic muscles possible?

Rotterdam Intrinsic Hand Myometer (RIHM)

RIHM clinically useful?

- Reliability
- Comparison with manual muscle strength testing
- Comparison with grip- and pinch dynamometers
- Sensitivity to detect loss of intrinsic muscle strength in patients
Test-retest reliability

| Test-retest reliability | Schreuders et al, Am J Hand Surg 2004 |

| Table 2. Reliability between Measurements in 20 Patients with Ulnar Nerve Lesion and Healthy Controls.

<table>
<thead>
<tr>
<th>Test</th>
<th>ICC</th>
<th>SEM</th>
<th>SD</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key grip</td>
<td>0.98</td>
<td>0.4</td>
<td>0.8</td>
<td>0.90-0.98</td>
</tr>
<tr>
<td>Oppon. thumb</td>
<td>0.98</td>
<td>0.4</td>
<td>0.8</td>
<td>0.90-0.98</td>
</tr>
<tr>
<td>Oppon. index</td>
<td>0.95</td>
<td>0.5</td>
<td>1.0</td>
<td>0.88-0.97</td>
</tr>
<tr>
<td>Oppon. little</td>
<td>0.91</td>
<td>0.6</td>
<td>1.2</td>
<td>0.74-0.95</td>
</tr>
</tbody>
</table>

Reliability of the Rotterdam Intrinsic Hand Myometer (RIHM) in children (aged 4-12)

| Comparison with manual muscle testing | Schreuders et al, J Hand Ther 2006 |

| Table 1. Comparison of RIHM and manual muscle testing in patients with ulnar nerve lesions > 2 years after trauma.

<table>
<thead>
<tr>
<th>Test</th>
<th>RIHM (%)</th>
<th>MRC 0-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25%</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>25%</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>25%</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>25%</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>25%</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>25%</td>
<td>0</td>
</tr>
</tbody>
</table>

Comparison with grip- and pinch dynamometers: peripheral nerve injury

| Comparison with grip- and pinch dynamometers | Schreuders et al, J Hand Ther 2006 |

| Comparison with grip- and pinch dynamometers: peripheral nerve injury | Schreuders et al, J Hand Ther 2006 |

| RIHM measurements were most strongly related to the modified Sollerman task, which measures fine motor task of the hand and fingers | Schreuders et al, J Hand Ther 2006 |

<table>
<thead>
<tr>
<th>Nerve injuries</th>
<th>RIHM - grip strength no significant correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIHM - pinch strength sign correlated</td>
<td></td>
</tr>
<tr>
<td>thumb abduction (R = 0.55)</td>
<td></td>
</tr>
<tr>
<td>opposition (R = 0.72)</td>
<td>Schreuders et al, J Hand Ther 2006</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CMT patients</th>
<th>RIHM, pinch, grip, and wrist muscle strength measurements evaluate different aspects of hand function in CMT disease.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIHM measurements were most strongly related to the modified Sollerman task, which measures fine motor task of the hand and fingers</td>
<td>Schreuders et al, J Hand Ther 2006</td>
</tr>
</tbody>
</table>
ALERT - RIHM dynamometry
Pre–postoperative grip strength in relation to TT surgery for Ulnar or combined ulnar and median palsy. How does grip strength relate to different TT procedures?

<table>
<thead>
<tr>
<th></th>
<th>Index</th>
<th>Middle</th>
<th>Ring</th>
<th>Small</th>
<th>Grip (SP)</th>
<th>Key pinch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>110</td>
<td>105</td>
<td>100</td>
<td>70</td>
<td>210</td>
<td>130</td>
</tr>
<tr>
<td>Left</td>
<td>75</td>
<td>100</td>
<td>65</td>
<td>45</td>
<td>130</td>
<td>100</td>
</tr>
</tbody>
</table>

L Hand: (Ulnar/median palsy: ECRL > intrinsic and FDS > thumb)
R Hand: normal

**Techniques**

First Dorsal Interosseous

- Hand in pronation
- Position the index finger in abduction + slight flexion MCP
- Ask patient to hold the finger
- If can: pressure if not; MRC <3
- Press at MCP of index
- Direction = plan of hand

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Case

- Male subject after hand trauma.
- Injured hand grip strength 1 month post-op: 180 N
- Injured hand grip strength 3 months post-op: 220 N
- Mean normative data: 370 N
- Contralateral hand: 250 N

Questions:
- Can you conclude that the injured hand improved?
- Is the injured hand still significantly weaker at three months post-op?

How significant or relevant is a change in strength at follow-up?

Errors are estimated in repeatability studies

- Traditionally: Intraclass correlation coefficient (between 0 and 1) are calculated
  - E.g., ICC of grip strength = 0.96 (Brown, J Hand Therapy, 2000)
- However: difficult to interpret

Errors estimated in repeatability studies

- Alternatively: use Smallest Detectable Difference (SDD) or minimal detectable change

Repeatability

- For example:
  - 95% SDD=35 N
- Means that:
  A difference between measurements of 35N can be considered a real (non error) change in an individual patient with 95% confidence
Case

- Injured hand grip strength 1 month post-op: 180 N
- Injured hand grip strength 3 months post-op: 220 N
- Mean normative data: 370 N
- Contralateral hand: 250 N
- SDD=35 N
  - Can you conclude that the injured hand improved?
    - 220-180=40.
    - 40 is larger than the SDD (35) -> significant improvement
  - Is the injured hand still significantly weaker at three months post-op?
    - 250-220=30
    - 30 is smaller than the SDD -> no significant difference

Example: SDD of hand strength in children

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>SDD (N)</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martin Vigorimeter</td>
<td>0.85</td>
<td>17.0</td>
<td>31.3%</td>
</tr>
<tr>
<td>Jamar dynamometer</td>
<td>0.96</td>
<td>30.6</td>
<td>25.1%</td>
</tr>
<tr>
<td>RIHM 1st Dorsal Interosseus</td>
<td>0.95</td>
<td>3.6</td>
<td>16.7%</td>
</tr>
<tr>
<td>RIHM Abductor Pollicis Brevis</td>
<td>0.96</td>
<td>3.9</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

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CASE STUDIES

Techniques

Flexor tendon injury

- Manual Muscle strength (MRC)
- Grip strength (Jamar)
- Intrinsic muscle strength (RIHM)
- Wrist strength (MicroFET)
- Pinch (Preston, Loode)

Patient with CMT (HMSN)

Progressive disease from distal-proximal
**Patient with CMT**

- Manual Muscle strength (MRC)
- Grip strength (Jamar)
- Intrinsic muscle strength (RIHM)
- Wrist strength (MicroFET)
- Pinch (Preston, Loode)

**CMC arrosis**

- Manual Muscle strength (MRC)
- Grip strength (Jamar)
- Intrinsic muscle strength (RIHM)
- Wrist strength (MicroFET)
- Pinch (Preston, Loode)

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Thank you for your attention

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www.erasmusmc.nl/revalidatie/hand
www.handweb.eu/RIHM/