Standardized Clinical Video Analysis of the Injured Runner

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I have no relevant financial relationships to disclose
Examination Components

History and Physical Examination
- understand training habits
- consider running-related goals
- identify physical impairments

Running Gait Analysis with Video
- characterize running mechanics
- determine landing posture
- develop tissue loading profile

Footwear Assessment (and Orthoses)
- classify level of support
- determine appropriateness of fit
- identify evidence of breakdown
Intake Form

- Facilitate history taking
- Describe training factors
- Define running-related goals
Running-Specific Outcome Tool

- Develop a running specific tool for assessing improvement following an injury that is valid, reliable, and sensitive to change for use in clinical practice and research

  - Condition specific tools (e.g., Kujala, Visa-A)
    - Limited assessment of return to sport
    - Limits research with diverse injuries

  - Body region specific tools (e.g., LEFS, FAOS)
    - Demonstrate significant ceiling effect
    - Too specific to a single region
University of Wisconsin Running Injury and Recovery Index (UWRI)
Development Process

1. Interview injured runners of all performance levels
2. 42 questions identified as factors relating to the running injury
3. Importance product: Assess question importance and relevance
4. 9 key questions identified and included in UWRI
5. Question clarification process with UWRI
University of Wisconsin Running Injury and Recovery Index

- Perfect score = 36
- Good psychometric properties:
  - test-retest reliability
  - Internal consistency
- MCID in progress

Physical Examination

- **Goals:**
  - Determine injury diagnosis/severity in combination with history
    - Identify involved tissues
  - Identify physical impairments and characterize musculoskeletal status
    - Consider all aspects relevant to running
    - Necessary to determine if running mechanics are an appropriate match
Motion Analysis Options

3D Lab

2D Camera
Reliability

- Orthopedic walking gait assessment
  - moderate inter-examiner reliability
  - good intra-examiner reliability
  - increased reliability with increased experience
    Brunnekreef (2005) BMC Musculoskeletal Dis

- Rearfoot motion during walking
  - poor inter-observer
  - poor-fair intra-observer

- improve reliability
  - systematic approach
  - likert-scale measures
  - experience
    Kotecki et al. (2013) J Orthop Sports Phys Ther
Assessing Running Mechanics

☐ 3 common questions:
   1. overground or treadmill?
   2. what type of camera?
   3. what type of video software?
## Treadmill or Not

<table>
<thead>
<tr>
<th></th>
<th>Overground</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological validity</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Control Speed</td>
<td>No*</td>
<td>Yes</td>
</tr>
<tr>
<td>Fixed relationship between camera and runner</td>
<td>No*</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*requires additional equipment
Are Mechanics Different on Treadmill?

- Step length is commonly reduced when running on a treadmill
- Running form normalizes within 6 min of treadmill running

Lavcanska et al. (2005) Hum Mov Sci

Treadmill Specifications

1. Stiff running deck
   - If too compliant, runner will adjust mechanics (e.g., increase lower extremity stiffness)

2. Regulated belt speed
   - If motor is underpowered, then the belt speed decreases at foot-ground contact

Equipment Set-up

- Cameras must be placed perpendicular to the plane of interest
  - Frontal plane is most sensitive
  - Transverse plane is inferred

- Adequate space for video capture from multiple angles
  - Able to view whole body from side and back

- Treadmill: 8-10 ft
- Camera height: 4 ft
Out of Plane Motion

Rearfoot-Shoe Eversion

Toe-out

Out of plane motion can create false positives for excessive motion.
What Camera?

**Sampling rate** (frames per second, fps)

- Influences the number of pictures you have to determine movement
  - Human eye ~16 samples/s
  - Video camera – 30-60 samples/s
  - Digital camera ≤ 1000 samples/s

- Observation alone is insufficient to capture body posture at specific events of the gait cycle
Maximum Pronation

- Barefoot walking
- Shod running
- Shod running with custom orthotics
Timing of Events

- Running speed of 3.83 m/s (8.57 mph or 7 min/mile)

- Time interval between samples:
  - Eye = 62.5 ms
  - Video camera (30 fps) = 33.3 ms
  - Video camera (60 fps) = 16.7 ms
  - High speed camera (100+ fps) = < 10 ms
High Speed Cameras

2000 fps

120 fps

www.photron.com
What about Video Software?

- **Benefits**
  - Potential to display 2 videos synchronously
  - Patient education
  - Database structure

- **Does not increase accuracy**
  - Still a 2D image
Phone and Tablet Options

- iPhone 6 records:
  - 60 fps at 1080p
  - 120/240 fps at 720p

- iPad Air 2 (not mini)
  - 120 fps at 720p

- Limitations
  - digital zoom

- Many video analysis Apps
  - UberSense
  - CoachMyVideo
  - iCoachView
EMR Considerations

- Video storage is rarely a basic feature of electronic medical record systems
  - Potential need for a custom-build

- Upload of report as PDF is feasible, but limits ability to search information when compiling data

- At minimum, need to ensure the interpretation of the video is included in examination for billing purposes
Joint Interaction

Lumbar Side Bend and Rotation

Pelvic Lateral Tilt

Femoral Internal Rotation

Knee Medial Collapse

Tibial Internal Rotation

Foot Pronation

From Hammer (1999). Aspen
No Single Optimum Form for All

- Physical differences prevent everyone from using the same form
  - Strength, bony structure, range of motion, tissue stiffness, mass distribution, general fitness, running history...

- Instead, there are key characteristics to avoid
  - Overstriding
  - Bounce
  - Compliance
Avoid Overstriding

- Foot inclination angle
- Heel-COM distance
- Knee flexion angle
- Tibial angle
Avoid Bounce

- COM vertical displacement

Maximum Height

Minimum Height
Avoid Excessive Compliance

- Partially reflected in COM vertical displacement
- Evaluate frontal plane collapse
- Joint center alignment
- Lateral pelvic tilt
- Knee separation
- Foot-COM placement
Key Parameters

- Focus on loading response (initial contact to mid-stance)
- Characterize body control during energy absorption
### Key Parameters

#### Frontal
- Midstance
  - Joint center alignment
  - Lateral pelvic tilt
  - Foot-COM placement
  - Knee separation
  - Rearfoot/shoe alignment

#### Sagittal
- Initial Contact
  - Foot-ground angle
  - Heel-COM distance
  - Knee flexion angle
  - Tibial angle
- Midstance
  - Max knee flexion angle
  - Max ankle dorsiflexion angle
- COM vertical displacement
Kinematic Predictors of Kinetics

Peak GRFv

Wille et al. (2014). J Orthop Sports Phys Ther
## Kinematic Predictors of Kinetics

### Braking Impulse

<table>
<thead>
<tr>
<th>Kinematic Predictor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step Rate</td>
<td>Heel to COM Distance at Initial Contact</td>
</tr>
<tr>
<td></td>
<td>Foot Inclination Angle at Initial Contact</td>
</tr>
<tr>
<td></td>
<td>Vertical Displacement of COM</td>
</tr>
</tbody>
</table>

**Braking Impulse**

\[ R^2 = 0.50 \]

Wille et al. (2014). J Orthop Sports Phys Ther
Kinematic Predictors of Kinetics
Energy Absorption at Knee

- Step Rate
- Foot Inclination Angle at Initial Contact
- Peak Knee Flexion during Stance

Mechanical Energy Absorbed about the Knee ($R^2=0.58$)

Wille et al. (2014). J Orthop Sports Phys Ther
Pseudo-quantitative Approach

- Estimate load to body based on posture at landing and midstance
- Use physical exam findings to interpret appropriateness of running mechanics
- Each parameter is assessed using 3-pt or 5-pt scale
  - Consideration for the inherent limitations with 2D video analysis

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Appropriate</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>-1</td>
<td></td>
<td>+1</td>
<td>+2</td>
</tr>
</tbody>
</table>

- Key parameters demonstrated strong agreement between raters ($\kappa > 0.80$)

Kotecki et al. (2013) J Orthop Sports Phys Ther
Joint Center Alignment
Midstance

<table>
<thead>
<tr>
<th>Lateral Deviation</th>
<th>Appropriate</th>
<th>Medial Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive lateral</td>
<td>Mild lateral</td>
<td>Appropriate (midline)</td>
</tr>
</tbody>
</table>

Common Injuries:
- PF pain
- ITB syndrome
- Greater trochanter syndrome
- Piriformis syndrome
Lateral Pelvic Tilt
Midstance

<table>
<thead>
<tr>
<th>Appropriate</th>
<th>Mild contralateral</th>
<th>Excessive contralateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3-5° males; 5-7° females)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- normal
- mild
- excessive

Common Injuries:
- Patellofemoral pain
- ITB syndrome
- Greater trochanter syndrome
- Piriformis syndrome
- Lumbopelvic pain
Foot-COM Placement at Midstance

- As running speed increases, this distance decreases

- Common Injuries:
  - MTSS
  - Bone stress injuries
  - Greater trochanter syndrome

<table>
<thead>
<tr>
<th>Appropriate</th>
<th>Mild crossover</th>
<th>Excessive crossover</th>
</tr>
</thead>
</table>

9:30 min/mile
Knee Separation at Midstance

<table>
<thead>
<tr>
<th>Narrow</th>
<th>Appropriate</th>
<th>Wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow with stance leg deviation</td>
<td>Narrow with swing leg deviation</td>
<td>Appropriate</td>
</tr>
</tbody>
</table>

- Narrow with stance leg deviation
- Narrow with swing leg deviation
- Appropriate
- Wide
Redundancy between Measures

- Lateral knee alignment
- Increased knee separation
- Narrow foot placement
# Foot Inclination Angle at Contact

<table>
<thead>
<tr>
<th>Heel-strike (&gt;10°)</th>
<th>Rearfoot</th>
<th>Midfoot</th>
<th>Forefoot</th>
</tr>
</thead>
</table>

The image shows a foot during a heel-strike, with an incline angle greater than 10°. The foot is transitioning from the heel to the midfoot phase of running.
Foot Inclination Angle at Contact

heel-strike  rearfoot  midfoot  forefoot
Horizontal Distance from Heel to COM at Contact
Knee Flexion Angle at Contact

<table>
<thead>
<tr>
<th>Excessive decrease</th>
<th>Mild decrease</th>
<th>Appropriate (~20°)</th>
<th>Mild increase</th>
<th>Excessive increase</th>
</tr>
</thead>
</table>

- Common Injuries:
  - Patellofemoral pain
  - Infrapatellar tendinopathy
  - ITB syndrome
  - Greater trochanter syndrome
  - Piriformis syndrome
Tibial Inclination Angle at Contact

<table>
<thead>
<tr>
<th>Vertical</th>
<th>Mild inclination</th>
<th>Excessive inclination</th>
</tr>
</thead>
</table>

Common Injuries:
- MTSS
- Bone stress injuries
- Exertional compartment syndrome
Maximum Knee Flexion Angle

<table>
<thead>
<tr>
<th>Excessive decrease</th>
<th>Mild decrease</th>
<th>Appropriate (~40°)</th>
<th>Mild increase</th>
<th>Excessive increase</th>
</tr>
</thead>
</table>

- Common Injuries:
  - Patellofemoral pain
  - Infrapatellar tendinopathy
  - ITB syndrome
  - Greater trochanter syndrome
## Ankle Dorsiflexion at Midstance

<table>
<thead>
<tr>
<th>Decrease</th>
<th>Appropriate (knees over toes)</th>
<th>Increase</th>
</tr>
</thead>
</table>

- **Common Injuries:**
  - Calf strains
  - Achilles tendinopathy
  - Plantar fasciitis

*Increased ankle dorsiflexion*
COM Vertical Displacement

<table>
<thead>
<tr>
<th>Appropriate (6-8cm)</th>
<th>Mild Increase</th>
<th>Excessive Increase</th>
</tr>
</thead>
</table>

Maximum Height

Mid-flight

Minimum Height

Midstance
Putting it all Together

- 17 y/o with chronic knee pain and tibial stress reactions

9:00 min/mile  168 steps/min
Lower Leg Injuries and Running

- Achilles tendinosis
- Calf strains
- Tibial stress injuries
- Exertional compartment syndrome
- Medial tibial stress syndrome

UW Neuromuscular Biomechanics Lab
Tibial Stress Injuries

- Mechanics of concern:
  - Impact loading rate
  - Braking impulse
  - Tibial inclination angle at initial contact
  - COM vertical displacement

- Meta-analysis results showed significant differences between the vertical loading rates of those with and without prior lower-limb stress fractures

  Zadpoor and Nikyooan (2011) Clin Biomech
Running Forces and Loading Rate

Force (BW)

GRF_v

active

passive / impact

Loading Rate

foot-strike

toe-off
Decreased Loading Rate

Graph showing force (BW) over time from foot-strike to toe-off. Different lines represent typical, decreased peak force, and decreased peak force and loading rate.
Braking Impulse

![Diagram showing the braking and propulsive forces during walking or running](image)

The diagram illustrates the braking and propulsive forces (GRF<sub>AP</sub>) acting on an individual during the stride. The forces are measured relative to body weight (BW) and are shown from foot-strike to toe-off.

**Foot-strike**:
- **Braking** force: negative GRF<sub>AP</sub> (force acting in the opposite direction to movement)
- **Propulsive** force: positive GRF<sub>AP</sub> (force aiding movement forward)

**Toe-off**:
- **Propulsive** force: increased as the body moves forward

The shaded area represents the impulse imparted to the body during the stride, highlighting the difference between braking and propulsive forces.
Stride Length

- Farther the foot hits the ground in front of the body’s COM (longer stride), the greater the braking impulse.

- Body has to overcome this braking impulse to maintain speed.
Kinematic Predictors of Kinetics

Braking Impulse

Polynomial coefficient \( R^2 = 0.50 \)

Wille et al. (2014). *J Orthop Sports Phys Ther*
Foot Inclination Angle at Contact

<table>
<thead>
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<th>Heel-strike (&gt;10°)</th>
<th>Rearfoot</th>
<th>Midfoot</th>
<th>Forefoot</th>
</tr>
</thead>
</table>

heel-strike  rearfoot  midfoot  forefoot
# Knee Flexion Angle

## Initial Contact

<table>
<thead>
<tr>
<th></th>
<th>Excessive decrease</th>
<th>Mild decrease</th>
<th>Appropriate (~20°)</th>
<th>Mild increase</th>
<th>Excessive increase</th>
</tr>
</thead>
</table>

- Excessive decrease
- Mild decrease
- Appropriate (~20°)
- Mild increase
- Excessive increase
Tibial Inclination Angle
Initial Contact

<table>
<thead>
<tr>
<th>Vertical</th>
<th>Mild inclination</th>
<th>Excessive inclination</th>
</tr>
</thead>
</table>

![Image of person running on a treadmill with tibial inclination angle highlighted]
Stride Length

- Reduction in stride length reduces risk of tibial stress injury

- positively effects:
  - loading rate
  - braking impulse
  - tibia inclination angle
  - COM vertical displacement

- Increasing step rate is simple strategy to teach/learn
  - Maintain constant speed
Step Rate and Tibial Accelerations

- Decreased tibial accelerations with increased step rate
  - Constant speed


- More vertical leg posture at initial contact

  Farley and Gonzalez (1996) *J Biomechanics*
Calf and Achilles Injuries

- Running mechanics of concern:
  - Peak ankle dorsiflexion during stance
  - COM vertical displacement
Provocative Running Mechanics

- Pain is typically during propulsive phase of stance (50-100%)
  - Generally not during loading response

- Excessive ankle dorsiflexion during midstance
  - Should be assessed relative to ankle dorsiflexion observed in weightbearing
  - Excessive strain and wrapping prior to initiation of concentric contraction

- If medial insertional pain, look for high rate of pronation during contact
Achilles Case

9:30 min/mile; 150 steps/min

☐ 37 y/o male
☐ Recurrent Achilles symptoms past 2 yrs
☐ Midportion tendon pain with palpation (5cm from insertion)
☐ Limited weightbearing DF
☐ COM vertical displacement ~11-12 cm
☐ Increased peak dorsiflexion in stance
How to Reduce Dorsiflexion Angle?

- Increased ankle dorsiflexion is related to increased knee flexion

- Reduce both by increasing lower extremity stiffness (increase step rate)
  - Spend less time on the ground

Morin et al. (2007) J Biomechanics
Farley and Gonzalez (1996) J Biomechanics
Heavy Load Eccentrics

- Proven benefit for Achilles tendinopathies
  - “2-up, 1-down”
  - Midportion and insertional, just change range

- Incorporate into recovery from calf strain, when appropriate
  - Generally after 7-10 days depending on severity

- Consider as preventative exercise for runners over age of 35 yr
  - Potentially slow the increased compliance of Achilles tendon associated with aging
Gastrocnemius Aponeurosis

Shear wave speed (m/s)

Age (years)

Dorsiflexed

Resting

Plantarflexed

Young

Middle-Aged

Case Outcome

- 4 wk follow-up
  - No pain or symptoms
  - 80% back to pre-injury level; remaining limitation is reduced mileage

Pre
9:30 min/mile @ 150 steps/min

4wks post
9:30 min/mile @ 160 steps/min
Medial Tibial Stress Syndrome

- Running mechanics of concern:
  - Foot-inclination angle
  - Midline cross-over
  - Foot pronation
  - Toe-out
Foot Placement

**Step Width**
- Decreases with increasing speed

**Relative to COM**
- Crossover

Cavanagh (1987) Foot Ankle
Bone Stress and Cross-over

- Tibial stress associated with step width
  - Greater compression along medial aspect of tibia with narrow step width

Meardon and Derrick (2014). J Biomech
Foot-COM Placement at Midstance

- Location of the foot with respect to the whole body’s line of gravity (LOG)
- As running speed increases, this distance decreases

9:30 min/mile
MTSS and Crossover
How to Reduce Cross-over?

- Increase step width
  - Verbal cueing
  - Mirror retraining

- Commonly overcorrected at start of retraining

- May influence performance
  - 9% net increase in metabolic power with 8% increase in step width
    - Arellano and Kram (2011) J Biomech

- Address gluteal muscle weakness/firing
  - Narrow step width may be strategy to create stable stance position thereby reducing need for muscular stabilization at hip
Exertional Compartment Syndrome

- Running mechanics of concern:
  - Foot-inclination angle
  - Ankle dorsiflexion during swing
    - Rate and magnitude
Forefoot Strike

- 2 patients with chronic exertional compartment syndrome
  - 1: 4yr history of bilateral symptoms
  - 2: 7 months s/p right fasciotomy with symptom return bilateral

- Retraining: emphasis on forefoot landing and Pose technique
  - 3x/wk (1hr each) for 6 weeks

- Clinical outcomes:
  - Reduced intracompartmental pressures post-running
  - 6wk F/U: GROC “great deal better”
  - 7 month F/U: still running pain-free


What about Swing Phase?

Increased rate and magnitude of dorsiflexion.
- Designed with the common clinician in mind
  - Minimal overhead
  - Reimbursable
  - 60min or less
Thank You

Madison, WI, USA