The Role of Local Mechanical Factors in the Pathogenesis of Knee Osteoarthritis: Implications for Rehabilitation Strategies

Emerging Prevention and Intervention Strategies for Knee Osteoarthritis that Target Mechanical Factors
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Disclosure
Nothing to disclose

Objectives
Discuss clinical evidence of modifying mechanical factors in management of knee OA

1. Global approach
   - weight loss, slow walking speed

2. Proximal approach
   - minimize contra-lateral pelvic drop, unilateral trunk lean

3. Local approach
   - quads strengthening, medial thrust gait, medial collapse gait, neuro-muscular training, elliptical training, knee unloading brace

4. Distal approach
   - toe-out gait, lateral wedge insole, footwear

Pathogenesis of knee OA
- Impaired knee local neuro-mechanical environment
- Systemic vulnerability
- Previous knee injuries
- Muscle weakness
- Malalignment
- Laxity & Instability
- Proprioception
- Vibratory perception threshold
- Genetic factors
- Obesity
- Aging

External knee adduction moment (KAM)
- 70% of the knee joint load passes thru the medial compartment due to the ground reaction force passing medial to the joint axis
- Torque closing medial compartment in stance phase of gait
- Strongly relates to medial load and medial compartment disease progression
- Often used as an indirect measure of medial joint loading in many biomechanical studies and load-modifying trials

External knee adduction moment (KAM)
- Hurwitz et al., 1998; Miyazaki et al., 2002; Bennell et al., 2011
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Global approach
• weight loss
• slow walking speed

Proximal approach
• control pelvic drop
• trunk lean

Local approach
• quads strengthening
• medial thrust & collapse gait
• neuro-muscular training
• elliptical training
• knee brace

Distal approach
• toe-out gait
• lateral wedge insole
• footwear

Weight loss
• Design: assessor-blinded RCT
• Participants: overweight or obese elderly with radiographic knee OA (n=76)
• Intervention: any of 4 interventions of exercise, diet, exercise + diet, healthy lifestyle (control)
• Outcome: peak knee compressive force, KAM
• Follow-up time: 18 months
• Findings: high weight loss group (10% change) had decreased peak knee compressive force, but no change in KAM

Weight loss - Caveat
➢ Other studies have shown that weight loss may reduce pain and improve function, however the mechanisms may not be completely related to reduced joint load
➢ Weight loss > 10% appears to be beneficial
➢ Knee malalignment may mediate the effect of weight loss on medial knee load

Weight loss
• Design: single group pre- and post-intervention comparison
• Participants: obese persons with knee OA (n=157)
• Intervention: diet
• Outcome: peak knee compressive force, KAM
• Follow-up time: 16 weeks
• Findings:
  - average wt loss: 13.5%
  - decreased peak knee compressive force and KAM
  - decreased pain and increased walking speed

Walking speed
• Design: single group within subject comparison
• Participants: persons with medial knee OA (n=44)
• Intervention: walking at self-selected vs. slow vs. fast speed
• Outcome: KAM (1st and 2nd peak)
• Follow-up time: immediate
• Findings:
  - Positive correlation between gait speed and 1st KAM, especially in knees with mild disease

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Walking speed

- **Design:** single group within subject comparison
- **Participants:** persons with knee OA (n=34)
- **Intervention:** fast vs. self-selected vs. slow walking speed on treadmill
- **Outcome:** peak KAM
- **Follow-up time:** immediate
- **Findings:**
  - In severe OA (K/L=4), slow speed resulted in a small KAM reduction; fast speed did not change KAM
  - In moderate OA (K/L=2-3), slow speed did not change KAM; fast speed resulted in a small KAM increase

(Zeni & Higginson, 2009)

Walking speed - Caveat

- The effects of walking speed on KAM are inconsistent
- More severe knee OA may not respond to gait speed change
- To cover the same distance, slower walking speed may require more gait cycles and may yield similar cumulative knee load
- Physical function may be affected with significantly lower walking speed

Walking speed

- **Design:** single group within subject comparison
- **Participants:** persons with knee OA (n=41)
- **Intervention:** increase gait speed to 150% of natural pace
- **Outcome:** peak KAM
- **Follow-up time:** immediate
- **Findings:**
  - no change in overall KAM magnitude
  - Increased 1st peak KAM and decreased 2nd peak KAM

(Landry et al, 2009)

Hip abductor strengthening

- **Design:** single group within subject comparison
- **Participants:** persons with medial knee OA (n=6)
- **Intervention:** strengthening ex. on hip abductors, quads, and hamstrings in both weight-bearing (WB) and non WB
- **Frequency:** 1:1 training session with a PT 3x/wk for 2 wks, then 1x/wk for 2 wks; home ex. on other days
- **Outcome:** peak KAM, pain, and function
- **Follow-up time:** 4 wks
- **Findings:**
  - 9% mean reduction of KAM
  - decreased pain and improved WOMAC function

(Thorp et al., 2010)
Hip abductor strengthening

- **Design**: non-equivalent control group (no knee OA or pain), within subject comparison
- **Participants**: with medial knee OA & controls (n=40 each)
- **Intervention**: home exercise programs of hip abductor strengthening in both WB and non-WB positions
- **Controls**: continue daily activities
- **Frequency**: home ex. 3-4x/wk for 8 wks
- **Outcome**: peak KAM, pain, and function
- **Follow-up time**: 8 wks
- **Findings**:
  - no change of peak KAM in both groups
  - decreased pain and improved chair-stand function in intervention group

(Fied et al., 2010)

Hip abductor strengthening

- **Design**: assessor-blinded RCT
- **Participants**: medial knee OA (n=39 in strengthening, n=37 in control)
- **Intervention**: supervised home exercise programs of hip abductor & adductor strengthening in both WB and non-WB
- **Controls**: no intervention
- **Frequency**: home ex. 5x/wk for 12 wks
- **Outcome**: peak KAM, pain, and function
- **Follow-up time**: 12 wks
- **Findings**:
  - no change of peak KAM in both groups
  - intervention group had ↑ contralateral pelvic drop
  - decreased pain and improved function

(Bennell et al., 2010)

Femoral brace

- **Design**: single group within subject comparison
- **Participants**: persons with medial knee OA (n=15)
- **Intervention**: use SERF (stability through ER of the femur) strap to promote hip ER and abduction during walking
- **Outcome**: peak KAM, pelvic drop angle, and pain
- **Follow-up time**: immediate
- **Findings**:
  - 28% reduction of peak KAM
  - 35% reduction of pain on VAS
  - decreased contra-lateral pelvis drop by 2°
  - increased ipsi-lateral hip abduction angle by 3°

(Wallace et al., 2010)

Hip control - Caveat

- **Hip abductor strengthening ex. program decreased pain and improved function, but it’s role in KAM reduction may be limited**
- **Other LE muscles were also strengthening in WB exercises**
- **Minimizing contra-lateral pelvic drop during gait significantly reduced medial knee load**
- **Gait training and motor control of hip movement during walking may be more beneficial than muscle strengthening alone**

Ipsi-lateral trunk lean

- **A compensatory gait strategy of rapid shift of body weight to the stance limb and lateral trunk sway to reduce external knee adduction moment (KAM)**

(Mundermann et al., 2005; Briem et al., 2009; Hunt et al., 2008 & 2010)

Ipsi-lateral trunk lean

- **Design**: single group within subject comparison
- **Participants**: young healthy (n=19)
- **Intervention**: instructed to move their trunk from side to side to self-selected amount during walking
- **Outcome**: peak KAM
- **Follow-up time**: immediate
- **Findings**:
  - mean lateral trunk lean angle = 10°
  - 64% reduction of 1st peak KAM
  - no change of 2nd peak KAM

(Mundermann et al., 2008)
Ipsi-lateral trunk lean

- **Design:** single group within subject comparison
- **Participants:** young healthy (n=9)
- **Intervention:** practiced to walk with 3 conditions of trunk lean (4°, 8°, and 12°), using real-time biofeedback of the actual trunk lean angle

(Hunt et al., 2011)

Ipsi-lateral trunk lean - Caveat

- Ipsi-lateral trunk lean during walking can significantly reduce KAM
- No trials on elderly persons with knee OA
- This movement pattern may help to reduce KAM, but may also perpetuate hip abductor weakness and adversely affect spinal mechanics
- Need to closely monitor adverse effects on other joints

Quadriceps strengthening

- **Design:** assessor-blinded RCT
- **Participants:** medial knee OA (n=49 in strengthening, n=48 in control)
- **Intervention:** supervised home exercise programs of quad strengthening in non-WB positions
- **Controls:** no intervention
- **Frequency:** home ex. 5x/wk for 12 wks
- **Outcome:** peak KAM, pain, and function
- **Follow-up time:** 12 wks
- **Findings:**
  - no change of peak KAM in both groups
  - pain reduction only in intervention group with neutrally-aligned knees
  - no change of physical function

(Lim et al., 2010)
**Quadriceps strengthening**

- **Findings:**
  - In OA knees, quad strengthening group had non-significant lower rate of OA progression than ROM group (18% vs. 28%, p = 0.094)
  - In knees that were radiographically normal at baseline, quad strengthening group had greater rate of joint space narrowing > 0.5mm than ROM group (34% vs. 19%, p = 0.038)
  - Both groups lost quadriceps strength at 30 months, though strengthening group had less strength loss

(Mikesky et al., 2006)

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**Factors contributing to varus mal-alignment or instability**

- Decreased passive tissue stiffness
- Loss of cartilage & meniscus
- Impaired sensory input
- Poor active muscular stabilization

Frontal plane instability/mal-alignment

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**Medial thrust gait**

- **Design:** single subject
- **Participants:** 37 y/o male with medial knee OA (K/L=2)
- **Intervention:** based on computer optimization, he was instructed to practice “medial thrust gait”
- **Outcome:** peak KAM
- **Follow-up time:** learning the new gait over 9 months
- **Findings:**
  - 50% reduction of KAM

(Fregly et al., 2007)

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**Medial collapse gait**

- **Design:** single group within subject comparison
- **Participants:** young healthy individuals with varus alignment (n=8)
- **Intervention:** treadmill walking with hip IR and adduction, using real-time biofeedback of the knee varus angle info
- **Outcome:** peak KAM
- **Follow-up time:** 8 sessions of training over 1 month
- **Findings:**
  - 19% reduction of KAM
  - knee varus angle ↓ by 2°

(Barrion et al., 2007)

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**Gait modification for varus thrust**

- **Design:** single subject
- **Participants:** 64 y/o female with medial knee OA and varus thrust during gait
- **Intervention:** gait modifications of ipsi-lateral trunk lean, ↑ toe-out angle (self-selected magnitude), lateral wedged insole, and custom-made foot orthotics
- **Outcome:** peak KAM
- **Follow-up time:** immediate
- **Findings:**
  - variable performance from trial to trial
  - both trunk lean and toe-out reduced KAM
  - only trunk lean ↓ varus thrust angle by 38%  (Hunt et al., 2011)

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**Quadriceps strengthening - Caveat**

- Focusing on quad strengthening alone may not beneficial
- Strengthening program should be tailored to knee subsets with different mechanical characteristics, such as varus/valgus mal-alignment or laxity
- Emphasize on proper knee dynamic alignment during all exercises and functional activities, i.e. maintaining neutral dynamic frontal and transverse alignment through motor control, foot orthotics, and bracing, or taping
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Gait modification with real-time feedback of KAM

• Design: single group within subject comparison
• Participants: young healthy (n=16)
• Intervention: real-time visual or vibratory feedback of the magnitude of peak KAM provided while walking on treadmill
• Outcome: peak KAM, awkwardness scale (0-10)
• Follow-up time: immediate
• Findings:
  - mean reduction of peak KAM = 21%, ranging from 3 to 50%
  - common strategies: toe-in (n=14), loading medial side of foot (n=6), increased trunk sway (n=4)
  - average awkwardness = 5.3

(Wheeler et al., 2011)

Gait modification - Caveat

➢ Modifying gait appears to be a promising approach to reduce medial knee load and dynamic varus instability, and may ultimately alter disease course
➢ Need to monitor kinematic and kinetic changes at other regions of body
➢ Medial thrust or collapse gait may harm PFJ
➢ Current research are very limited; studies on elderly with knee OA and larger-scale RCTs are needed
➢ Long-term effects and retention of the modified gait patterns are unknown

Neuro-muscular training

• Design: single group within subject comparison
• Participants: women with early radiographic knee OA (K/L I or II) (n=11)
• Intervention: LE strengthening and neuromuscular training in WB
• Frequency: 2x/wk
• Outcome: peak KAM (during one-leg rise from stool and during gait)
• Follow-up time: 8 wks
• Findings:
  - reduction of KAM observed during lone-leg rise, but not during gait

(Thorstensson et al., 2007)

Neuro-muscular training

• Design: assessor-blinded RCT
• Participants: knee OA (n=91 in treatment, n=92 in control)
• Intervention: agility and perturbation training + standard ex. therapy
• Controls: arm bike activity + standard ex. therapy
• Frequency: 12 supervised sessions in 6-8 wks, continue ex. 2x/wk
• Outcome: function and pain
• Follow-up time: 2-, 6, and 12-month follow-up periods
• Findings:
  - improved self-reported function in both groups
  - no change in pain or performance-based function in either group

(Fitzgerald et al., 2011)

Examples

Courtesy of Dr. Kelly Fitzgerald

Examples

Courtesy of Dr. Kelly Fitzgerald

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Elliptical neuromuscular training

- Design: single subject
- Participants: 43 y/o male with medial knee OA and varus thrust during gait
- Intervention: training on the modified elliptical exerciser, responding to frontal plane perturbation by the footplate
- Frequency: 3x/wk
- Outcome: function, pain, and subjective report of instability
- Follow-up time: 6 weeks
- Findings:
  - 25% and 18% improvement in pain and function respectively
  - resolution of complaints of instability
  - frontal plane stability improved from 2.05 to 1.08cm
  (Chang et al., 2011)

Neuromuscular training - Caveat

- Neuromuscular training targeting knee frontal and transverse plane motor control during functional weight bearing activities may be beneficial
- Frontal plane stability may be improved via programmed external varus-valgus perturbation

Unloading knee brace

- Previous studies have shown that knee valgus unloading brace reduced peak KAM by 13% to 25% during the stance phase of gait
  (Pollo et al., 2002; Self et al., 2000)
- Clinical trials showed variable and inconsistent improvement in pain and function
  (Brouwer et al., 2005; Krohn, 2005)

Unloading knee brace - caveat

- Neoprene or hinged brace may also be beneficial for reducing muscle co-contraction
- Unloading knee brace may be used only in more intense physical activities, such as tennis or jogging
- Women tend to have compliance issue
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**Global approach**
- weight loss
- slow gait speed

**Proximal approach**
- control pelvic drop
- trunk lean

**Local approach**
- strengthening
- medial thrust & collapse gait
- neuro-muscular training
- elliptical training
- knee brace

**Distal approach**
- toe-out gait
- lateral wedge insole
- footwear

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**Toe-out gait**

- **Design:** single group within subject comparison
- **Participants:** persons with mild to moderate knee OA (n=9)
- **Intervention:** increase toe-out angle by 15° during gait, using visual cues of lines drawn on the force plate
- **Outcome:** 1st and 2nd peak KAM
- **Follow-up time:** immediate
- **Findings:**
  - 55% reduction of 2nd peak KAM
  - no change of 1st peak KAM

*(Guo et al, 2007)*

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**Toe-out gait**

- **Design:** single group within subject comparison
- **Participants:** persons with knee OA (n=12)
- **Intervention:** three walking conditions (1) natural foot angle (2) toe-out (3) toe-in
- **Outcome:** 1st and 2nd peak KAM
- **Follow-up time:** immediate
- **Findings:**
  - toe-out gait ↓ 2nd peak KAM, did not change the 1st peak KAM
  - toe-in gait did not change KAM values

*(Lynn and Costigan, 2008)*

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**Toe-out gait - Caveat**

- Walking with toe-out may help to reduce 2nd peak KAM
- Potential sources of out-toeing
  1. tibial ER
  2. hip ER
  3. combination of both

**Caution:** not to compromise the normal function of the foot, knee, and hip

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**Lateral wedged insole**

- **Lateral wedged insole**
  - moves the center of pressure laterally
  - reduce the moment arm of ground reaction force acting at the knee joint
  - decrease KAM and lessen the medial joint load
- 2-year RCT demonstrated reduced intake of NSAIDS, but no change of pain/function or slow disease progression
  *(Pham et al., 2004)*
- 6-wk double-blinded randomized crossover trial showed no clinically meaningful improvement in pain
  *(Baker et al., 2007)*
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**Lateral wedged insole**
- **Design**: participant-blinded RCT
- **Participants**: medial knee OA (n=20 in treatment, n=25 in control)
- **Intervention**: 5°-15° full length insole worn daily for 12 months
  - Posting determined by pain response during 8” lateral step down, non-responders eliminated from the study
  - Participants wore standardized walking shoes
- **Controls**: neutral insole without wedging
- **Outcome**: WOMAC pain, function
- **Follow-up time**: insole worn daily for 12 months
- **Findings**:
  - Both groups improved in pain and function
  - Neutral insole did as well as the lateral wedged one
  - Standardized footwear may contribute to favorable outcomes in both groups (Barrios et al., 2009)

**Lateral wedged insole - Caveat**
- Variations in shoe types or ankle/foot characteristics may mediate the biomechanical effects of wedge insole
- Classify patients into subgroups of responders vs. non
- Use a wedge at about 5° and full length
- Daily use of 5-10 hours
- Persons with less severe disease, younger age, and less obesity tend to benefit more
- Patients with immediate favorable responses tend to have greatest long-term functional gain and pain reduction
- Monitor potential problems with ankle/foot with use of wedges

**Footwear**
- Gait studies showed that barefoot walking had lower KAM than walking with shoes in persons with medial knee OA – ranging from 7.4-11.9% (Shakoor et al., 2006; Kemp et al., 2008)
- Mechanism of why barefoot walking reduces knee load is unclear, possibly due to:
  - Reduce peak ground reaction force
  - Promote mid-foot strike and minimize impact transient
  - Increase foot intrinsic muscle activity
  - Enhance proprioceptive inputs
  - Shoes that simulate barefoot walking may be beneficial

**Footwear – mobility shoe**
- **Design**: single group within group comparison
- **Participants**: persons with medial knee OA; n=28 and 20 in groups A and B respectively
- **Intervention**:
  - Group A: mobility shoe vs. self-selected walking shoe vs. barefoot
  - Group B: mobility shoe vs. control stability shoe vs. barefoot
- **Outcome**: peak KAM and KAM impulse
- **Follow-up time**: immediate
- **Findings**:
  - Group A - the specialized mobility shoe reduced KAM by 8% when comparing with self-selected walking shoe
  - Group B - the specialized mobility shoe reduced KAM by 12% when comparing with control stability shoe
  - Long-term disease modifying effect of this novel mobility shoe is unknown (Shakoor et al., 2008)
**Footwear – variable stiffness shoe**

- **Design**: participant-blinded RCT
- **Participants**: medial knee OA (n=32 in treatment, n=23 in control)
- **Intervention**: variable-stiffness sole worn daily

  ![](image)

- **Controls**: shoe with constant stiffness on both sides
- **Outcome**: within-day peak KAM, WOMAC pain, function
- **Follow-up time**: one year
- **Findings**: both groups improved in pain and function when compared to personal shoe, 4.7% ↓ of KAM in variable stiffness shoe, 3% ↑ in control shoes (Erhart-Hedik et al., 2011)

**Footwear – APOS shoe**

- **Design**: single group within subject comparison
- **Participants**: women with medial knee OA (n=25)
- **Intervention**: as a biomechanical treatment device, wearing APOS shoe to change center of pressure location and provide perturbation during walking
- **Outcome**: barefoot peak KAM and KAM impulse, WOMAC pain, function
- **Follow-up time**: 3 and 9 months
- **Findings**: improved in pain and function at both 3 and 9 months - 13%, 8.4%, and 12.7% reduction in KAM impulse, 1st peak KAM and 2nd peak KAM (Holm et al., 2011)

**Footwear - Caveat**

- The role of footwear in management of knee OA is complex; more evidence and RCT with structural outcomes are needed for sound recommendations
- Flat-heel shoes may be worn in preference to > 1.5 inch heels
- Flexible/mobility shoes may provide mobility needed to mimic barefoot walking and reduce knee load
- Variable-stiffness sole with stiffer lateral side may help to reduce medial knee load and improve symptoms
- Patients with pathologies associated with pronatory foot type may not benefit from flexible/mobile shoes and lateral wedge

**Summary**

- Variability in individual neuro-mechanical characteristics and adaptation
  - classify into different sub-groups
  - responders vs. non-responders
- Each intervention approach may have its pros and cons
  - single vs. combination intervention approach
- Limited RCT on these approaches
  - need for RCT with structural outcomes