Optimizing Muscle & Bone Strength: The Role of Physical Activity During Aging

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28% of women and 37% of men with a hip fracture will die within 1 year.

Osteoporotic fractures cost $2.3 billion annually in Canada.

Up to 30% of older adults are affected by sarcopenia and 20% have a functional disability.

1 in 3 women and 1 in 5 men will have an osteoporotic fracture.
Osteo-sarcopenia & frailty

Osteoporosis
Sarcopenia

Frailty
- Physical inactivity
- Weight loss
- Malnutrition
- Fatigue
- Social isolation
- Cognitive impairment

Functional Impairment
- Muscle weakness
- Slow gait speed
- Poor balance

Falls & Fractures

Modified from: Cesari et al. Front Aging Neurosci, 2014
Muscle & bone loss with aging

Young (18-25 years) muscle

Sarcopenic (>65 years) muscle

Peak Bone Mass

Menopause

Increased Risk

Bone Mass

Age

0 20 40 60 80

Men

Women

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Pathways to osteoporotic fractures

- Aging
- Physical inactivity
- Falls risk

↓ Muscle & bone strength
↓ Physical function

Osteoporotic fractures
The functional muscle-bone unit

Challenges

Increase in
- Bone length
- Muscle force

Bone strength

Bone architecture
Bone mass

Regulatory feedback loop

Tissue strain
Set point
Mechanostat

Effector signals

Osteoblasts
Osteoclasts

Hormones, nutrition, behavioral, environmental factors

Modulators

Sarcopenia

Loss of muscle mass and strength with aging

- ↓ "muscle building" stimuli (hormones, protein, exercise)
- ↓ # muscle cells and muscle fiber size
- ↓ muscle endurance and power
- ↑ muscle fatigue and exercise difficulty
- ↑ risk of falls, fractures, and frailty

Cruz-Jentoft et al. Age Ageing, 2010
Clinical definitions of sarcopenia

- European Working Group on Sarcopenia in Older People (EWGSOP)
- Foundation for National Institutes of Health Sarcopenia Project (FNIH)

<table>
<thead>
<tr>
<th>Muscle Parameter</th>
<th>EWGSOP Definition</th>
<th>FNIH Definition</th>
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<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
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<tr>
<td>Low muscle mass</td>
<td>ALM/hgt^2 ≤ 7.26 kg/m^2</td>
<td>ALM/hgt^2 ≤ 5.45 kg/m^2</td>
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<tr>
<td>Low grip strength</td>
<td>&lt; 30 kg</td>
<td>&lt; 20 kg</td>
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<tr>
<td>Slow gait speed</td>
<td>≤ 0.8 m/s</td>
<td>≤ 0.8 m/s</td>
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</tbody>
</table>

Note: ALM = appendicular lean mass
Sarcopenia & fracture risk

Combined effect size = 1.34, 95% CI = 1.13-1.58, P=0.001, 9 studies

Zhang et al. Osteoporos Int, 2018
Low appendicular lean mass is a modifiable risk factor for low BMD

Rikkonen et al. Calcif Tissue Int, 2012
Relationship between appendicular lean mass index and bone strength

Gibbs JC et al. Bone, 2017

Dual energy x-ray absorptiometry (DXA)

High resolution pQCT

Normal lean muscle mass

Low lean muscle mass
ALMI was a positive correlate of failure load

Distal radius

\[ r = 0.657, p<0.001 \]

Distal tibia

\[ r = 0.695, p<0.001 \]

Gibbs JC et al. Bone, 2017
**ALMI is associated with bone strength**

<table>
<thead>
<tr>
<th></th>
<th>Adjusted associations&lt;sup&gt;a&lt;/sup&gt;</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>b (SE)</td>
<td>P</td>
<td>R²</td>
</tr>
<tr>
<td><strong>Distal radius</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Failure load</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ALMI</td>
<td>122.0 (32.0)</td>
<td>&lt;0.001</td>
<td>0.645</td>
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<tr>
<td>Ultimate stress</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ALMI</td>
<td>1.1 (0.7)</td>
<td>0.095</td>
<td>0.178</td>
</tr>
<tr>
<td><strong>Distal tibia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALMI</td>
<td>432.0 (75.0)</td>
<td>&lt;0.001</td>
<td>0.594</td>
</tr>
<tr>
<td>Ultimate stress</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALMI</td>
<td>1.4 (0.6)</td>
<td>0.020</td>
<td>0.178</td>
</tr>
</tbody>
</table>

<sup>a</sup> = Adjusted for age, sex, prior fracture, calcium supplementation, estrogen replacement, osteoporosis medication use, and glucocorticoid use.

Gibbs JC et al. Bone, 2017
Weight loss is associated with muscle and bone loss

Frimel TN et al. MSSE, 2008
Resistance exercise + diet for preventing muscle & bone loss

A) Whole-body Lean Mass

B) Total Hip aBMD

Villareal DT et al. NEJM, 2017
Pathways to osteoporotic fractures: aging

Resistance Training + Nutrition

↑ Muscle mass
↑ Muscle strength

↑ Failure load
↑ BMD

↓ Frailty risk
↓ Fracture risk
Effects of exercise on BMD: postmenopausal women

General (if all studies are pooled):
- +0.85% LS BMD

Effect may vary by activity:
- High-force dynamic: hip BMD +1.55%, no effect LS
- Low-force dynamic: LS BMD +0.87%, no effect hip
- Progressive resistance training: LS BMD +0.86%, FN BMD +1.03%
- Low weights had no effect on BMD
- Combination programs: +3.22% LS BMD, +0.45% FN BMD

Note: LS = lumbar spine; FN = femoral neck; BMD = bone mineral density

Howe et al. Cochrane Data Syst Rev, 2011
Effects of exercise on BMD: older men

Kelley, Kelley & Kohrt, Bone 2013 Meta-analysis:
• “…moderate and statistically significant improvement….at the femoral neck…. while a small trend was observed at the spine”
• “…insufficient evidence to recommend exercise as a intervention for improving and/or maintaining BMD in men”

Allison et al, JBMR 2013: High-impact unilateral exercise
• Femoral neck BMD ↑0.7% in exercise leg, ↓ 0.9% in control leg
• CSMI, section modulus ↑ in exercise leg, not in control leg
• Small n, lack of intention-to-treat analysis

Cochrane meta-analysis in process!

Note: BMD = bone mineral density
CSMI – cross sectional moment of inertia
High-intensity resistance & impact training improves BMD

8 months of twice-weekly, 30-minute, supervised HiRIT (5 sets of 5 repetitions, >85% 1-RM OR home-based, low-intensity exercise program (CON)

A) Lumbar Spine BMD (% change)
CON (n=43) HiRIT (n=43)
-1.2 2.9

B) Femoral Neck BMD (% change)
CON (n=43) HiRIT (n=43)
-2 0.3

Watson et al. JBMR, 2017
What is Too Fit To Fracture?

Identify what we know
Synthesize and evaluate evidence, develop recommendations using GRADE process
http://www.grade...workinggroup.org/index.htm

Domains:
• Assessment
• Therapeutic goals
• Exercise and physical activity

Establish expert consensus
Delphi consensus process

Exercise and physical activity recommendations for individuals with osteoporosis

Establish research priorities, plans for action

Research to Action!
Recommendations: Exercise and Physical Activity

Expert consensus and best evidence support:

1. Strength training ≥ 2x/wk
2. Balance training daily
3. Exercises for back extensor muscles daily
4. ≥ 30min/day aerobic physical activity
5. Spine sparing strategies like hip hinge and step-to-turn can ↓ spine loads → how to move, rather than how not to move

Strength Training

Involves using muscles to generate force against resistance

At least twice a week, 8-12 repetitions

One exercise for each major muscle group:
- Lower legs
- Upper legs
- Chest
- Back
- Shoulders
- Arms

Use: Free weights, weight-training machines, exercise bands, lifting body weight against gravity (e.g., push-up on wall or counter, squat exercise)
Balance Training

- Challenge your balance daily!
- Can do without wavering for > 5 seconds but < 30 seconds
- Can be done in one place, or moving around
- Progressively ↑ the challenge is important

Find a class in your community that includes balance exercises, or get help selecting the right exercises for you.
Challenge your Balance Daily to Prevent Falls

Reduce your base of support
- Stand with feet together or on 1 leg (see photo).
- Balance on your heels only or on your toes only.
- Walk while you balance on your toes or heels only.
- Stand with 1 foot in front of the other. Your front heel touches your back toes.

Respond to things that upset your balance
- Correct your balance after something upsets your balance. For example, catch a ball and correct your balance.
- Balance on an unstable surface. For example, a piece of foam or a BOSU ball. A BOSU ball has a flat bottom and a round top. It doesn’t roll.

Do activities that require coordination or shifting weight while moving around
- Dance.
- Do Tai Chi.
- Walk heel to toe in a line or in a figure eight.

Shift your weight
- Move your weight more to 1 foot than the other.
- Lean side to side or front to back.
- Shift your weight from toes to heels.
Aerobic Physical Activity

≥ 150 min moderate-to-vigorous physical activity a week or ≥ 30 min/day

Move every 30 min!

Weight-bearing aerobic physical activity, like walking or dancing

Those with vertebral fracture should aim for moderate intensity only

If you are at high risk of fracture, unfamiliar with exercise, or have other health problems, start at a low intensity and progress to moderate intensity.

Posture Training

• 5-10 min/day – posture exercises, posture cues during daily activities
• Attention to alignment > intensity
• Start with “Shavasana” and looking at posture in the mirror
• Progress to active exercise to improve back extensors endurance on advice of a Bone Fit™ trained professional!
**Exercise for improving outcomes after osteoporotic vertebral fracture**

Exercise versus Control (After 4 to 12 weeks)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Studies</th>
<th>Participants</th>
<th>Effect Estimate MD (IV, Fixed, 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timed Up and Go</td>
<td>3</td>
<td>139</td>
<td>-1.09 [-1.78, -0.40]</td>
</tr>
</tbody>
</table>
Exercise improves mobility & muscle function after vertebral fracture

- Bergland et al. Osteoporos Int, 2011
- Bennell et al. BMC Musculoskeletal Disorders, 2010
Pathways to osteoporotic fractures: physical inactivity

Resistance, balance & aerobic training

Multicomponent Exercise

↑ BMD
↑ Mobility
- QoL, pain, posture

↓ Fracture risk

Considerations:
- Adherence
- Behaviour change
- Level of supervision
Fall prevention with exercise

• 21% less likely to fall if participating in exercise

• Greatest effects – 39% less likely to fall – in programs that:
  ▪ Had ≥3 hrs/week of exercise
  ▪ High balance challenge

Low muscle quality & strength are associated with higher falls risk

<table>
<thead>
<tr>
<th>Muscle outcome</th>
<th>Falls risk z-score (n=551)</th>
<th>B (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low lower-limb muscle quality (kg/kg)</td>
<td>0.41 (0.19, 0.62)</td>
<td></td>
</tr>
<tr>
<td>Low upper-limb muscle quality (kg/kg)</td>
<td>0.29 (0.07, 0.51)</td>
<td></td>
</tr>
<tr>
<td>Low lower-limb muscle strength (kg)</td>
<td>0.60 (0.39, 0.81)</td>
<td></td>
</tr>
<tr>
<td>Low handgrip muscle strength (kg)</td>
<td>0.50 (0.27, 0.73)</td>
<td></td>
</tr>
<tr>
<td>Low appendicular lean mass index (kg/m²)</td>
<td>0.03 (-0.19, 0.25)</td>
<td></td>
</tr>
<tr>
<td>Low ALM/BMI (kg/kg/m²)</td>
<td>0.08 (-0.15, 0.32)</td>
<td></td>
</tr>
</tbody>
</table>

Data in bold indicate statistical significant at p<0.05.

Balogun et al. J Nutr Health Aging, 2017
Lifestyle functional exercise is effective in reducing rate of falls

Reduction of 31% in rate of falls compared with controls (IRR: 0.69, 95% CI 0.48 to 0.99)

↑ static & dynamic balance
↑ balance confidence

↑ lower-leg strength
↑ late life function index

↑ self-report physical activity

Clemson et al. BMJ, 2012
Mi-LiFE feasibility study

• Pilot feasibility study – RE-AIM
• Family health team primary care practice
• 48 sedentary older adults (81±5 yrs, 62% women, 49±87 min/wk of MVPA), medically cleared for exercise

Methods: Intervention

• 1 individual and 4 groups sessions with PT
• Balance and strength exercises and behaviour change education
• Participants received manual of exercises and activity planner

Reach: Recruitment

Screened for initial eligibility (n = 759)
- Excluded (n = 625)
  - Not meeting inclusion criteria (n = 335)
  - Declined to participate (n = 290)

Referred to Mi-LiFE program (n = 134)
- Excluded (n = 86)
  - Not meeting inclusion criteria (n = 11)
  - Declined to participate (n = 69)
  - Unreachable (n = 6)

Eligible and interested
Completed study visit #1 (n = 48)

Enrolled in intervention (n = 44)
- Withdrew prior to intervention (n = 4)

Gibbs JC et al. Can J Aging, under review
Effectiveness: Strength and balance activity increased following Mi-LiFE

<table>
<thead>
<tr>
<th></th>
<th>Baseline Mean (SD)</th>
<th>Follow-up Mean (SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPAQ-Strength PA (min/week)</td>
<td>37.1 (73.1)</td>
<td>64.3 (94.5)</td>
<td>0.026*</td>
</tr>
<tr>
<td>IPAQ-Balance PA (min/week)</td>
<td>6.9 (26.1)</td>
<td>41.3 (48.4)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>IPAQ-MVPA (min/week)</td>
<td>41.2 (80.6)</td>
<td>60.6 (125.1)</td>
<td>0.881*</td>
</tr>
<tr>
<td>IPAQ-Walking (min/week)</td>
<td>116.8 (143.0)</td>
<td>107.2 (123.0)</td>
<td>0.709</td>
</tr>
<tr>
<td>IPAQ-Sedentary time (hr/day)</td>
<td>6.8 (3.1)</td>
<td>7.5 (3.5)</td>
<td>0.314</td>
</tr>
<tr>
<td>MVPA (min/week)</td>
<td>58.6 (111.1)</td>
<td>52.5 (96.8)</td>
<td>0.881*</td>
</tr>
<tr>
<td>Light activity (min/week)</td>
<td>1323.0 (558.9)</td>
<td>1223.4 (504.7)</td>
<td>0.292</td>
</tr>
<tr>
<td>Sedentary time (min/week)</td>
<td>4497.2 (787.1)</td>
<td>4607.0 (880.8)</td>
<td>0.404</td>
</tr>
</tbody>
</table>

MVPA = Moderate-to-vigorous PA; IPAQ = International PA Questionnaire
* = Wilcoxon rank-sum tests were performed for non-normally distributed data.
Effectiveness: Health-related quality of life, not physical function, improved

Gibbs JC et al. Can J Aging, under review
Adherence

Gibbs JC et al. Can J Aging, under review

Withdrew prior 1-2 sessions 3-4 sessions 5 sessions

Session Attendance (%) 0 10 20 30 40 50 60 70

Adherence ≥3d/wk (%) 0 10 20 30 40 50 60 70

Weeks 1-8 Weeks 9-16 Weeks 17-24

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# Implementation

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<tr>
<th>Capability</th>
<th>Opportunity</th>
<th>Motivation</th>
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<tbody>
<tr>
<td>- Deliverer training - program &amp; behaviour change</td>
<td>- Caregiver involvement</td>
<td>- Diverse participants’ goals and intentions</td>
</tr>
<tr>
<td></td>
<td>- Participants’ knowledge &amp; self-efficacy</td>
<td>- Behaviour change techniques</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Intensive follow-up</td>
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</tr>
</tbody>
</table>

Gibbs JC et al. Can J Aging, under review
Michie S et al. ABC of behaviour change theories (2 ed), 2014
**67% of participants completed follow-up**

Gibbs JC et al. Can J Aging, under review
Pathways to osteoporotic fractures: falls

Group Exercise → Strength & balance training

↑ Functional muscle strength
↑ Dynamic balance
- Physical activity

↓ Fall risk
↓ Fracture risk

Considerations:
• Feasibility
• Adherence
• Behaviour change
• Lifestyle vs. structured
Putting research into action

Resources:
• Use Osteoporosis Canada’s tools: videos, booklet, one pager [www.osteoporosis.ca/osteoporosis-and-you/too-fit-to-fracture/](http://www.osteoporosis.ca/osteoporosis-and-you/too-fit-to-fracture/)
• Bone Fit Trained Physiotherapist or Kinesiologist [www.bonefit.ca](http://www.bonefit.ca)
• Exercise sheets for fitness instructors
• Slides for teaching/continuing education
How can we optimize muscle & bone strength to prevent fractures?

- Resistance Training & Adequate Nutrition
- Multicomponent Exercise
- Strength & Balance Training
How can we optimize muscle & bone strength to prevent fractures?

- Physical Activity
- Adequate Nutrition
- Fall Prevention

- Quality of Life
- Social Participation
- Health Behaviour Change

- Muscle & Bone Strength
- Body Composition
- Physical Function

- Mobility
  - \( \downarrow \) Frailty Risk
  - \( \downarrow \) Fracture Risk
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Mi-LiFE Investigator Team
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[Logos of funding agencies]
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