Obesity Drives the Metabolic Syndrome in Spinal Cord Injury

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Disclosures

The presenters of this session have nothing to disclose.

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Objectives

- Describe causative and relationship components of the metabolic syndrome
- Review the relationship between physical inactivity, body composition and secondary morbidities after SCI
- Review nutritional concepts of caloric density and nutrient density in promoting fat loss
- Associate various forms of physical activities with long term physical and psychological benefits for those with SCI
- Discuss potential risks & benefits of bariatric surgical options for persons with SCI
Objective 1

- Describe causative and relationship components of the metabolic syndrome

Criteria for Clinical Diagnosis of the Metabolic Syndrome

- Elevated waist circumference
- Elevated triglycerides
- Reduced HDL-C
- Elevated blood pressure
  - (Systolic >130 and/or diastolic >85 mm Hg)
- Elevated fasting glucose
Metabolic Syndrome

- Central Obesity
- Insulin Resistance
- Hypertension
- Dyslipidemia
  - High Triglycerides
  - Low HDL-cholesterol
Metabolic Syndrome

<table>
<thead>
<tr>
<th>TABLE 1. ATP III Clinical Identification of the Metabolic Syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Factor</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Abdominal obesity, given as waist circumference*†</td>
</tr>
<tr>
<td>Men</td>
</tr>
<tr>
<td>Women</td>
</tr>
<tr>
<td>Triglycerides</td>
</tr>
<tr>
<td>HDL cholesterol</td>
</tr>
<tr>
<td>Men</td>
</tr>
<tr>
<td>Woman</td>
</tr>
<tr>
<td>Blood pressure</td>
</tr>
<tr>
<td>Fasting glucose</td>
</tr>
</tbody>
</table>

*Overweight and obesity are associated with insulin resistance and the metabolic syndrome. However, the presence of abdominal obesity is more highly correlated with the metabolic risk factors than is an elevated BMI. Therefore, the simple measure of waist circumference is recommended to identify the body weight component of the metabolic syndrome.

†Some male patients can develop multiple metabolic risk factors when the waist circumference is only marginally increased, eg, 94 to 102 cm (37 to 39 in). Such patients may have a strong genetic contribution to insulin resistance. They should benefit from changes in lifestyle habits, similarly to men with categorial increases in waist circumference.

‡The American Diabetes Association has recently established a cutpoint of ≥100 mg/dL, above which persons have either prediabetes (impaired fasting glucose) or diabetes. This new cutpoint should be applicable for identifying the lower boundary to define an elevated glucose as one criterion for the metabolic syndrome.

<table>
<thead>
<tr>
<th>TABLE 2. WHO Clinical Criteria for Metabolic Syndrome*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulin resistance, identified by 1 of the following:</td>
</tr>
<tr>
<td>• Type 2 diabetes</td>
</tr>
<tr>
<td>• Impaired fasting glucose</td>
</tr>
<tr>
<td>• Impaired glucose tolerance</td>
</tr>
<tr>
<td>• or for those with normal fasting glucose levels (&lt;110 mg/dL), glucose uptake below the lowest quartile for background population under investigation under hyperinsulinemic, euglycemic conditions</td>
</tr>
</tbody>
</table>

Plus any 2 of the following:

• Antihypertensive medication and/or high blood pressure (≥140 mm Hg systolic or ≥90 mm Hg diastolic)
• Plasma triglycerides ≥150 mg/dL (≥1.7 mmol/L)
• HDL cholesterol <35 mg/dL (<0.9 mmol/L) in men or <39 mg/dL (1.0 mmol/L) in women
• BMI >30 kg/m² and/or waist:hip ratio >0.9 in men, >0.85 in women
• Urinary albumin excretion rate ≥20 μg/min or albumin:creatinine ratio ≥30 mg/g

*Derived from Alberti et al.7,8
Metabolic Syndrome: IDF Updated Definition

- Central Obesity (Waist Circumference)
  - European Men $\geq 94$ cm (37”) or US Men $\geq 102$ cm (40”)
  - European Women $\geq 80$ cm (31.5”) or US Women $\geq 88$ cm (34.5”)
- Plus any two of the following:
  - TG $\geq 150$ mg/dl (1.7 mmol/L) or under Rx
  - Low HDL-cholesterol or under Rx
    - Men $< 40$ mg/dl (1.03 mmol/L)
    - Women $< 50$ mg/dl (1.29 mmol/L)
  - Elevated Blood Pressure or under Rx
    - SBP $\geq 130$ mmHg or DBP $\geq 85$ mm Hg
  - Fasting Plasma Glucose $\geq 100$ mg/dl (5.6 mmol/L)

IDF Consensus Panel, August 2005
Holt (2005) Diabetes, Obesity & Metab 7(5):618
Metabolic Syndrome in SCI

Evidence Report / Technology Assessment
- AHRQ January 2008 (#163)

Executive Summary:
- Methods
  - Minimum ≥ 100 Subjects
  - 1996-2007 English articles
- Results
  - Evidence for prevalence, impact & outcomes of CHO & Lipid abnormalities in SCI is weak
  - Limited by few studies, small n, no control group, confounding variables, variations in reporting outcome measures
  - BMI is not reliable for assessing obesity in SCI
- Conclusion
  - Evidence does not support using different thresholds to define or treat CHO or Lipid abnormalities in SCI compared to AB adults
Metabolic Syndrome in SCI

  - 185 men with SCI 1:1 matched with able-bodied men
  - Similar prevalence of Metabolic Syndrome (AHA NHLBI) in both groups
    - SCI 30.8%
    - AB 28.6%
  - No difference in central obesity
  - Significantly lower:
    - TC, HDL, LDL, TG and Fasting Glucose

Arch Phys Med Rehabil 2007; 88:1198-204.
Metabolic Syndrome in SCI

  - N=41, Motor Complete Paraplegia
  - NLOI: T6-L1
  - 29% HTN (BP ≥ 140/90)
  - 76% had HDL <40 mg%
    - (42% < 35 mg%)
  - 34% had Metabolic Syndrome (ATP III)

Metabolic Syndrome in SCI?

- N=487 vets w/ SCI
- Mean Age: 55.2 y.o.
- 48.7% Tetra
- 56.5% BMI > 25 kg/m²
- 37% Dyslipidemia or Rx
  - 63.4% HDL-c < 40 mg%
- 48.7% FBG > 100 mg% or Rx
- 56.5% HTN
- 44.8% IDF Metabolic Syndrome

Gater et al, In Prep, JRRD
Rx Metabolic Syndrome

- **Diet and Exercise to ↓ obesity**
- Sibutramine
  - Inhibits Norepinephrine reuptake
  - SSRI
- Orlistat
  - Inhibits pancreatic lipase
  - Blocks intestinal lipid absorption
- Metformin (Biguanide)
  - Hepatic Insulin sensitivity
    - ↓ Hepatic gluconeogenesis & glycolysis
  - ↑ Muscle GLUT4 & Glycogenesis
- Glitizones (Thiazolidinediones)
  - Insulin sensitivity @ muscle/fat
  - ↑HDL-c, ↓LDL-c & TG
- Antihypertensives
- Lipid-lowering agents
Dangers of Obesity

- Hypertension
- Dyslipidemia
- Type 2 (non-insulin dependent) diabetes
- Insulin resistance, glucose intolerance
- Hyperinsulinemia
- Coronary heart disease
- Angina pectoris
- Congestive heart failure
- Stroke
- Gallstones

- Cholecystitis & cholelithiasis
- Gout
- Osteoarthritis
- Obstructive sleep apnea
- Some types of cancer (e.g., Breast, Prostate, Colon)
- Complications of pregnancy
- Poor female reproductive health
- Urinary stress incontinence
- Uric acid nephrolithiasis
- Psychological disorders (e.g. Depression)
1. Adipocytes Impair Fibrinolysis

- Fibrinolysis (Clot breakdown)
  - Prevents thrombus formation
- Adipocytes Secrete
  - Thrombin-Activatable Fibrinolysis Inhibitor (TAFI)
  - Plasminogen Activator Inhibitor-1 (PAI-1)
- TAFI & PAI-1 impair fibrinolysis
  - ↑ Risk of Thromboemboli

*Diabetes Care* 28:2211-2216, 2005
2. Adipocytes are Proinflammatory

- Adipocytes secrete:
  - Interleukin-6 (IL-6)
  - Tumor Necrosis Factor-α (TNF-α)
  - C-Reactive Protein (CRP)
  - Nuclear Factor Kappa B (NFκB)
  - Nitrous Oxide
    - Vasoconstriction
  - Leukocyte Adhesion
  - Endothelial Cell Apoptosis

*Diabetes Care* 27:2960-2965, 2004
*Diabetes Care* 27:2033-2040, 2004
Vascular Inflammation in SCI

- **Manns et al, 2005**
  - Abdominal sagittal diameter associated with CRP in SCI

- **Frost et al, 2005**
  - ↑ CRP in SCI vs. AB Controls

- **Lee et al, 2005**
  - hsCRP elevated in SCI
  - hsCRP significantly higher in those with metabolic syndrome
3. Adipocytes cause Hypertension

- Adipocytes Secrete:
  - Angiotensinogen
    - Potent Vasoconstrictor
  - Renin-Angiotensin-Aldosterone Syndrome
  - IL-6 → CRP → ↓ NO
    - Diminished Vasodilation
  - Free-Fatty Acids (FFA)

- Atherogenesis
  - Poor Compliance Arterioles

- Unusual HTN in SCI
  - Weaver et al, JSCIM 2007
    - N=7,959 vets w/ SCI&D
    - 39% BP 120/79-139/89
    - 23% BP >140/90
      - 25% Para
      - 16% Tetra
4. Visceral Fat causes dylipidemia

- Visceral Fat
  - Non-esterified Fatty Acids (NEFA)
  - Accumulate in Portal Circulation
  - Liver becomes overwhelmed
    - LDL-c & VLDL-c increases
    - HDL-c diminishes
Dyslipidemia in SCI

- **Bauman et al, 1992**
  - T.Chol  HDL
    - Tetraplegics  188  40 ± 1
    - Paraplegics  191  37 ± 1
    - AB Controls  210  48 ± 2

- **Zlotolow et al, 1992**
  - Serum HDL in SCI veterans was 35±2 vs. 49±2 in age-matched AB Controls

- **Tharion et al, 1998**
  - 58% SCI individuals with ↓ HDL; Only 2% with ↑ T.Chol

- **Bauman & Spungen, TSCIR 2007**
  - 63% SCI had HDL<40mg%
  - 44% SCI had HDL < 35 mg%
  - 19% SCI had HDL<30mg%
5. Adipocytes cause Insulin Resistance

- Adipocytes secrete:
  - IL-6
  - TNF-\(\alpha\)
  - Resulting CRP highly associated with insulin resistance

- Accumulation of FFA @ liver and skeletal muscle impair insulin sensitivity
  - FFA diminish glucose concentration gradient
  - PI-3 Kinase Cascade Inhibition
    - Fatty acyl CoA
    - Diacylglycerol
    - Ceramides

*Diabetes Care* 28:2322-2325, 2005

*Diabetes Care* 27:2960-2965, 2004
Glucose Transporters

GLUT4

PI 3-Kinase

GLUT4<sub>i</sub>, GLUT4<sub>A</sub>
Non-Esterifed FAs Inhibit Insulin-Signaling Cascade
Glucose Intolerance in SCI

- Hyperinsulinemia & IGT
  - Bauman & Spungen, 1994
    - 34% SCI Impaired Glucose Tolerance (IGT)
    - Additional 22% SCI Frank DM
  - Bauman et al, 1999
    - Impaired Glucose Tolerance
      - 73% Tetra Complete
      - 44% Tetra Incomplete
      - 24% Para Complete
      - 31% Para Incomplete
  - LaVela et al, 2006
    - 20% SCI&D veterans reported DM diagnosis (self-report)
Impaired Glucose Tolerance

Glucose during OGTT in SCI

\[ a \] indicates between group differences, \( p<0.05 \)

\[ b \] indicates between group differences, \( p<0.05 \)

C7-L2 (All) SCI Glucose AUC vs. % Body Fat
(4-Compartment Model)

$r = 0.671, p < 0.001$
T6-L2 Paraplegia Glucose AUC vs. % Body Fat
(4-Compartment Model)

$r=0.86, p<0.001$
Obesity In SCI

- Obesity is at epidemic proportions in SCI
- Obesity is a 2° Condition of SCI due to:
  - Obligatory sarcopenia
  - Blunted Anabolism
  - Blunted Sympathetic NS
  - Positive Energy Balance
- Obesity mediates:
  - Insulin Resistance
  - Hypertension
  - Dyslipidemia
  - Thromboembolism
  - Coronary Artery Disease
Energy Balance

Energy Expenditure = Energy Intake
Resting Energy Requirements

- Liver: 29%
- Brain: 19%
- Skeletal Muscle: 18%
- Heart: 10%
- Kidney: 7%
Relationship Between REE & FFM

\[ \text{REE} = 24.6 \times \text{FFM} + 175 \]

REE (kcal/day)

Fat-Free Mass (kg)
Acute Energy Needs after SCI

- **Harris Benedict Equation for Males**:  
  - English: BMR=66.5 + 6.24 (wt in #) + 12.707 (ht in ”) – 6.775 (age in yrs)  
  - Metric: BMR = 66.5 + 13.75 (wt in Kg) + 5.003 (ht in cm) – 6.775 (age in yrs)

- **Harris Benedict Equation for Females**:  
  - English: 655.1 + 4.35 (wt in #) + 4.7 (ht in ”) – 4.7 (age in yrs)  
  - Metric: 655.1 + 9.563 (wt in Kg) + 1.850 (ht in cm) – 4.676 (age in yrs)

- Example: 24 y.o. man, 160#, 6’1” after C4 Complete SCI
  - **Predicted BMR**: 66 + 6.23 (160#) + 12.7 (73) – 6.8 (24) = 1826.7 Kcal/d  
    - Sedentary Correction (1.2): 1826.7 x 1.2 = 2192 Kcal/d  
    - Stress Correction (1.6): 1826.7 x 1.6 = 2922.7 Kcal/d  
  - **Actual REE** = 1280 Kcal/d (43.8% Predicted TDEE)  
  - Represents 1642.7 Kcal/d Positive Energy Balance  
    - 11498.9 Kcal/wk (3.2# Fat accumulation/wk)  
    - 49281 Kcal/month (14.1# Fat accumulation/month)

Acute Obligatory N₂ Loss

- Rodriguez et al, 1991
  - Provided SCI vs. Non-SCI
    - 120% Predicted EE (Calories)
    - 2.4 g Protein/kg IBW/d
  - Continued N₂ loss in SCI until Wk 8
  - N₂ Balance achieved in Non-SCI by Wk 3

- Rodriguez et al, 1997
  - Inappropriate to use PEE, especially not:
    - 1.2 Multiplier (Activity Factor for Bed rest)
    - 1.6 Multiplier (Injury Factor for Major Trauma)

- Obligatory Sarcopenia
  - Muscle atrophy due to Paralysis
  - REE diminishes with N₂ loss

BMI Underestimates Obesity in SCI

  - Complete Para TDEE 2072 Kcal/d
  - Non-paraplegia TDEE 2582 Kcal/d
  - LBM ↓ 8.9 kg in SCI
  - Fat ↑ 7.1 kg > in SCI
- Bauman et al, JRRD, 2004
  - Total Body Potassium
    - 2,534 in SCI
    - 3,515 in MZ Twin
- Laughton et al, Spinal Cord, 2009
  - SCI BMI>22 kg/m^2 @ risk for obesity
    - BIA %BF
    - CRP
# SCI vs. Able Body % Fat

<table>
<thead>
<tr>
<th>Authors</th>
<th>Number</th>
<th>SCI</th>
<th>Activity</th>
<th>Gender</th>
<th>Age (Yrs)</th>
<th>BMI (kg/m²)</th>
<th>SCI %BF</th>
<th>AB %BF</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buchholz et al, 2003</td>
<td>28</td>
<td>Para</td>
<td>Sedentary</td>
<td>M/F</td>
<td>29.1</td>
<td>23.5</td>
<td>30.8</td>
<td>22.8</td>
<td>D2O Dilution</td>
</tr>
<tr>
<td>Bulbanian et al, 1987</td>
<td>22</td>
<td>Para</td>
<td>Active</td>
<td>M</td>
<td>27.5</td>
<td>22.3</td>
<td>22.4</td>
<td>11.3</td>
<td>Hydrodensitometry</td>
</tr>
<tr>
<td>Clasey &amp; Gater, 2006</td>
<td>13</td>
<td>Para</td>
<td>Sedentary</td>
<td>M/F</td>
<td>37.1</td>
<td>24.3</td>
<td>27.7</td>
<td>NA</td>
<td>4-C Model</td>
</tr>
<tr>
<td>George et al, 1988</td>
<td>15</td>
<td>Para/Tetra</td>
<td>Sedentary</td>
<td>M/F</td>
<td>30.8</td>
<td>22.3</td>
<td>25.5</td>
<td>20.2</td>
<td>Hydrodensitometry</td>
</tr>
<tr>
<td>Jones et al, 2003</td>
<td>20</td>
<td>Para/Tetra</td>
<td>Sedentary</td>
<td>M</td>
<td>16-52</td>
<td>23.1</td>
<td>27.5</td>
<td>18.1</td>
<td>DXA</td>
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<tr>
<td>Lussier et al, 1983</td>
<td>2</td>
<td>Para</td>
<td>Active</td>
<td>F</td>
<td>30.5</td>
<td>17.9</td>
<td>30.5</td>
<td>NA</td>
<td>Hydrodensitometry</td>
</tr>
<tr>
<td>Maggioni et al, 2003</td>
<td>13</td>
<td>Para</td>
<td>Sedentary</td>
<td>M</td>
<td>33.8</td>
<td>25.7</td>
<td>31.1</td>
<td>20.8</td>
<td>DXA</td>
</tr>
<tr>
<td>Spungen et al, 2000</td>
<td>8</td>
<td>Para</td>
<td>Sedentary</td>
<td>M</td>
<td>40</td>
<td>22.3</td>
<td>33.5</td>
<td>26.3</td>
<td>DXA</td>
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<tr>
<td>Spungen et al, 2003</td>
<td>66</td>
<td>Tetra</td>
<td>Sedentary</td>
<td>M</td>
<td>40</td>
<td>25.4</td>
<td>36.3</td>
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<td>DXA</td>
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<tr>
<td></td>
<td>67</td>
<td>Para</td>
<td>Sedentary</td>
<td>M</td>
<td>37</td>
<td>25.8</td>
<td>34.2</td>
<td>24.2</td>
<td>DXA</td>
</tr>
</tbody>
</table>

SCI=Spinal Cord Injury, Para=Paraplegia, Tetra=Tetraplegia, M=Male, F=Female, AB=Able Body Controls, %BF=Per cent Body Fat, D2O=Deuterium Dilution, 4-C Model=Four-Compartment Model, DXA=Dual-energy X-ray Absorptiometry, NA=Not Applicable

Objective 2

- Review the relationship between physical activity, body composition and secondary morbidities after SCI
Daily Energy Expenditure

- Resting Metabolic Rate (RMR): 60-75%
- Thermic Effect of Meal (TEM): 7-10%
- Thermic Effect of Activity (TEA): 15-30%

7-10 %

60-75%
Total Daily Energy Expenditure

TDEE: 2800 Kcal/day

TDEE: 2240 Kcal/day
Positive Energy Balance

Energy Expenditure $<$ Energy Intake

EE = 2240 Kcal/day
EI = 2440 Kcal/day

Net gain: 73,000 Kcal/year = 21lbs Fat/year
Energy Balance

Energy Expenditure = Energy Intake

EE = 2340 Kcal/day
EI = 2340 Kcal/day
Optimal Body Weight?

- Height/weight tables
- Body Mass Index (BMI)
  - Body Weight (Kg) / Height (m²)
- Body composition assessment
  - Laboratory techniques
  - Field techniques, e.g. skinfold fat
Body Composition Assessment
Cadaver Analyses

- **Body Density**
  - Fat = 0.901 g/cc
  - FFB = 1.100 g/cc
    - Water = 0.9937 g/cc (73.8%)
    - Protein = 1.340 g/cc (19.4%)
    - Mineral = 3.038 g/cc (6.8%)

- **Based on:**
  - 3 Male Cadavers
  - Ages 25, 35, 46 y.o.
  - Brozek et al, 1963
Hydrodensitometry

- Comparison
  - Weight in Air
    - Gold = Gold/Silver Alloy
  - Weight in Water
    - Gold > Gold/Silver Alloy

\[
Db = \frac{Wa}{[(Wa-Ww)/Dw]-(RV+100)}
\]

- Body Composition by Densitometry
  - Fat-Free Mass > Fat
  - \% Fat =\([(4.57/Db)-4.142]\)100
    - Brozek et al, 1963
  - \% Fat =\([(4.95/Db)-4.50]\)100
    - Siri, 1961

- Favorable Comparison
  - Subject Db = 1.0500 g/cc
  - Brozek Equation: 21.0\%
  - Siri Equation: 21.4\% Body Fat
Hydrodensitometry

**Assumptions**

- Fat Density = 0.901 g/cc
- FFM Density = 1.100 g/cc
- Fat & FFB Densities are the same for all individuals
- FFB tissue densities (H2O, Protein & Mineral) are constant & proportionally constant between individuals
- Individual differs from Reference Body only in amount of Fat, i.e.,
  - Water 73.8%
  - Protein 19.4%
  - Mineral 6.8%
- Residual Lung Volume is accurately determined
Air Displacement Plethysmography

- **Archimedes’ Principle**
  - Body weight and air displacement to determine $D_b$, less
  - Transthoracic Lung Volume (TLV)

- **Assumptions**
  - Similar to Hydrodensitometry, plus accurate TLV

- **Advantages**
  - ↓ Risk of aspiration, spasms, hypothermia
  - Comfort

- **Disadvantages**
  - Expensive
  - Poorly estimates TLV for SCI > T6
Anthropometry

- Combination of:
  - Lengths / Breadths
  - Circumferences
  - Skinfold Thicknesses

- Equations for Body Fat Determination
  - Validated by Hydrodensitometry
    - Similar assumptions, plus:
      - Muscle relaxed and hydrated
      - No musculoskeletal Abnormalities
      - Measurement sites are accurate
      - Tissue composition is independent of tissue size

- Advantages
  - Inexpensive and Accessible

- Disadvantages
  - Inappropriate for special populations
Bioelectrical Impedance Analysis (BIA)

- **Methodology**
  - Electricity passed through the body is impeded by fat

- **Assumptions:**
  - The Human Body is shaped like a perfect cylinder with uniform length & cross-sectional area
  - At a fixed frequency signal, impedance (Z) to current flow thru the body is related to conductor length (L) and inversely related to cross sectional area (A)
  - \( V = \rho L^2 / Z \), where
    - \( V = \) Volume of FFB (or TBW)
    - \( \rho = \) Resistivity Constant
    - \( L = \) Length (Height)
    - \( R = \) Resistance
BIA Guidelines

- **Advantages:**
  - Rapid, Non-invasive, Non-intrusive

- **Disadvantages:**
  - Hydrodensitometry-derived Equations
  - Hydration dependent
  - Not validated for SCI

- **Guidelines:**
  - No eating or drinking within 4 hours of the test
  - No exercise within 12 hours of the test
  - Urinate within 30 minutes of the test
  - No alcohol consumption within 48 hours of the test
  - No diuretic medications within 7 days of the test
  - No testing during water retention stage of menstrual cycle
Dual Energy X-ray Absorptiometry

- X-ray tube with filter converts polychromatic x-ray beam into low and high energy peaks
  - Provides proportion of Fat and FFB in each pixel
  - Fat content estimated from the assumed constant attenuation of pure fat ($R_f$) and of bone-free lean tissue ($R_l$)

Assumptions
- Constant values for $R_f$ and $R_l$
- Measures are not affected by anterior-posterior body thickness
- Fat content within unmeasured pixels (65% total pixels) is same as in measured pixels
Body Composition by DXA

- Advantages
  - Quick
  - Convenient
  - Non-invasive
  - Regional Estimates of Body Comp

- Disadvantages
  - Expensive
  - Hydration-dependent
  - Position-dependent
  - Lost pixels (Masked by bone)
  - Instrument variability
Compartment Modeling

- **Classic 2-Compartment**
  - Cadaver Analysis
    - Fat Mass
    - Fat-Free Body Mass

- **3-Compartment Model**
  - Fat Mass
  - Fat Free Body
    - Total Body Water
    - Fat-Free Dry Mass

- **4-Compartment Model**
  - Fat Mass
  - Fat-Free Body
    - Total Body Water
    - Bone
    - Residual Dry Mass
Body Composition in SCI

- 4-Compartment Modeling
  - “Gold Standard” (Heymsfeld et al, 1990)
  - Employs 3 Techniques
    - Hydrodensitometry
    - DXA
    - Deuterium ($\text{D}_2\text{O}$) Dilution or BIA
  - Compartments include:
    - Fat
    - Total Body Water
    - Bone
    - Residual Dry Mass
Obesity / Overfat in SCI

- Weaver et al, 2007
  - 33% Veterans OW
  - 20% Frankly Obese
  - 22% HTN

- Spungen et al, 2003
  - Tetra (n=66) 36.3% BF
  - Para (n=67) 34.2% BF

- Clasey & Gater, 2006
  - Para (n=13) 27.2 %BF

Body Mass Index in VAMC SCI Population
Recent Estimates

- Gupta et al, 2006
  - Spinal Cord 44:92-94
    - Site: Milwaukee VAMC
    - N=408, Mean Age 55.8
    - Body Mass Index
      - Underweight 3.6%
      - Normal Weight 27.9%
      - Overweight 35.9%
      - Obese 30.0%
    - Paraplegia > Tetraplegia
      - Reflects ↑FFM in Para + Body Fat Mass

Body Mass Index in Milwaukee SCI VAMC Population

- Underwt
- Normal
- OverWt
- Obese

4%
29%
31%
36%
## Preliminary Findings

### Body Composition Error in SCI

<table>
<thead>
<tr>
<th>(n=29)</th>
<th>Mean ± SE</th>
<th>Range</th>
<th>r</th>
<th>Total Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Comp %Fat</td>
<td>29.3 ± 2.6</td>
<td>7.0 - 62.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DXA %Fat</td>
<td>30.3 ± 2.2</td>
<td>10.0 - 63.1</td>
<td>0.73*</td>
<td>7.1 %</td>
</tr>
<tr>
<td>UWW %Fat</td>
<td>28.3 ± 2.5</td>
<td>4.8 - 57.0</td>
<td>0.81*</td>
<td>6.0 %</td>
</tr>
<tr>
<td>BIA %Fat</td>
<td>23.5 ± 1.9*</td>
<td>8.4 - 57.1</td>
<td>0.57*</td>
<td>11.1 %</td>
</tr>
<tr>
<td>J&amp;P %Fat</td>
<td>13.2 ± 1.5*</td>
<td>0.3 - 35.3</td>
<td>0.53*</td>
<td>18.7 %</td>
</tr>
</tbody>
</table>

*p<0.01 vs 4 Comp %Fat

4 Comp %Fat: Heymsfield, Am J Clin Nutr 52:52-8, 1990
Body Composition in SCI

- Body Fat
  - Increased vs. Able-Bodied
  - Distribution Differences?
- Fat-Free Body Mass
  - ↓FFB vs. Able-Bodied
    - Cardus & McTaggart, 1985
    - Spungen et al, 1992
  - ↓Bone Density
    - Biering-Sorenson et al, 1988
    - Finsen et al, 1992
  - ↓Total Body Water
    - Rasmann Nuhlicek et al, 1988
Objective 3

- Review nutritional concepts of caloric density and nutrient density to promote fat loss
Weight Loss Guidelines

- **Caloric Balance**
  - **Caloric Intake**
    - Fat (9 kcal/g)
    - ETOH (7 kcal/g)
    - CHO & Protein (4 kcal/g)
    - Fiber (2 Kcal/g)
    - 3500 cal = 1 pound fat
  - **Caloric Expenditure**
    - Aerobic
      - Uses CHO & fat as fuel
      - Maintains LBM
    - Anaerobic
      - Uses CHO (& fat) as fuel
      - Increases LBM (& BMR)

- **Recommendations**
  - Intake $\geq$ 1200 kcal/day
  - Acceptable foods
    - Cost, Taste
    - Preparation time
  - Maximal weight loss of 1 kg/week
  - Behavior Modification
  - Exercise Expenditure
    - $\geq$ 300-500 kcal/day, i.e.,
    - 1000-2000 cal/week
Caloric Requirements in SCI

- Tetraplegia
  - 15-20 lbs < IBW
  - Intake 10.3 Kcal/lb/d

- Paraplegia
  - 10-15 lbs < IBW
  - Intake 12.7 Kcal/lb/d

- Obese: Use \( IBW_{Adj} \)
  - \( [(WT_{actual} - IBW) \times 0.25] + IBW \)
Protein

- 20% Total Calories
- Adequate protein is needed for wound healing and to prevent pressure ulcers
- For patients at high risk of pressure ulcers, protein needs are 1.2 – 1.5 g/kg/d
- With complicated or nonhealing wounds, protein needs are 1.5-2 g/kg/d
- For long term health, protein requirements are 0.8 – 1.2 g/kg/day
Carbohydrates

- 50-60% Total Calories
- Choose whole grains and whole grain products
- Limit refined carbohydrates
- Include legumes regularly
- Include 6 to 10 small servings of fruits and vegetables each day
Fats

- Total fat for most individuals should be no more than 30% of total calories
  - Avoid fried foods
  - Limit added fats
  - Limit high fat snack foods
  - Make thoughtful choices when dining out
Cardiovascular Risk Reduction:

- Saturated fats no more than 7-10% total calories
  - Lean meats, poultry, and fish
  - Low fat or fat free dairy products
- The most heart healthy fats are the monounsaturates
  - Olive, canola or peanut oil
  - Olives and avocado
  - Nuts, seeds, and nut butters
- Fiber
  - 25-35 g Total Fiber/day
  - 10-15g Water Soluble Fiber/d
High Nutrient / Caloric Density

Eat rarely

Eat ≤1X Weekly

Eat ≤2X Weekly

Eat ≤1X Day

Unlimited

Unlimited

Best Nutrient/Calorie Ratio
- Green Vegetables
- Raw Vegetables
- Beans & Legumes
- Eggplant & Mushrooms
- Tomatoes & Peppers
- Fresh Fruit

Worst Nutrient/Calorie Ratio
- Flour & Sugar
- Oil
- Alcohol

- Beef, sweets, cheese, milk, processed foods, hydrogenated oils
- Poultry, eggs, oils
- Fish, fat-free dairy
- Whole grains, raw nuts, seeds
- Fruits, beans, legumes
- Vegetables (1/2 cooked / 1/2 raw)
Objective 4

- Associate various forms of physical activities with long term physical and psychological benefits for those with SCI.
Basic Exercise Physiology

- Body Composition
  - 4C Modeling
  - Visceral Fat
- CAD Risk Reduction
  - Insulin Sensitivity
  - Lipid Profile
  - Vascular Inflammation
  - HTN
- Aerobic Exercise
  - VO$_{2\text{Peak}}$
  - Energy Expenditure
  - Substrate Utilization
  - Thermoregulation
- Anaerobic Exercise
  - Strength / Power
  - Hypertrophy
- Motor Control & Neurorecovery
Prescription

- Diagnosis & Comorbidities
- Goals:
  - Specificity of Testing
  - Specificity of Training
- Limitations
- Environment
- Mode
- Frequency
- Intensity
- Duration
- Progression
Limitations

- Adaptive Cardiomyopathy
- Circulatory Hypokinesis
- Restrictive Lung Disease
- Obstructive Lung Disease
- Obesity
  - Vascular Inflammation
  - Impaired Fibrinolysis
  - Hypertension
  - Insulin Resistance
- Autonomic Dysreflexia
- Metabolic Deficiency
- Anabolic Deficiency
- Osteopenia
- Orthopedic
- Peripheral Neuropathy
- Pain
  - Nociceptive (↑↔↓ LOI)
  - Neuropathic (↑↔↓ LOI)
- Facility Access
- Transportation
- Temperature / Humidity
- Monitoring Expertise
Why Screen?

- Identification & exclusion of those with medical contraindications to exercise
- ID those at risk for disease who should undergo medical evaluation and exercise testing before starting an exercise program due to:
  - Age
  - Symptoms, &/or
  - Risk factors
- ID those with special needs
## Exercise Screening (ACSM)

### CAD Risk Factors
- **Family Hx**
  - Male 1 Relative < 55 y.o.
  - Female 1 Relative < 65 y.o.
- **Cigarette Smoking**
- **Hypertension**
  - SBP ≥140 or DBP ≥ 90 (>2x)
- **Hypercholesterolemia**
  - Total >200 mg%
  - HDL <40 mg%
  - LDL >100 mg%
- **Fasting Glucose ≥ 100 mg%**
- **Obesity**
  - BMI 30 kg/m² or Waist >100 cm
- **Sedentary Lifestyle**

### Major Signs or Symptoms
- **Anginal equivalent at chest, neck, jaw, arms**
- **Dyspnea on exertion**
- **Dizziness or syncope**
- **Orthopnea or Paroxysmal Nocturnal Dyspnea**
- **Ankle Edema**
- **Palpitations or tachycardia**
- **Intermittent claudication**
- **Known heart murmur**
- **Unusual fatigue or dyspnea with usual activities**
ACSM Recommendations for (A) Current PE/GXT & (B) MD Supervision during GXT

<table>
<thead>
<tr>
<th>Planned Exercise</th>
<th>Low Risk</th>
<th>Moderate Risk</th>
<th>High Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Current Physical Examination &amp; Graded Exercise Test</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate (3-6 METs)</td>
<td>Unnecessary</td>
<td>Unnecessary</td>
<td>Recommended</td>
</tr>
<tr>
<td>Vigorous (&gt;6 METs)</td>
<td>Unnecessary</td>
<td>Recommended</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>B. Physician Supervision During Graded Exercise Test</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submaximal GXT</td>
<td>Unnecessary</td>
<td>Unnecessary</td>
<td>Recommended</td>
</tr>
<tr>
<td>Maximal GXT</td>
<td>Unnecessary</td>
<td>Recommended</td>
<td>Recommended</td>
</tr>
</tbody>
</table>

**Low Risk:** Younger (M<45, W<55) individuals who are asymptomatic and meet no more than one risk factor threshold from previous slide

**Moderate Risk:** Older individuals or those who meet the threshold of 2 risk factors

**High Risk:** Individuals with signs/symptoms listed on previous slide, or known cardiovascular, pulmonary or metabolic disease

*ACSM Guidelines, 2005*
UE vs. LE Activity

UE Work = 74-80% LE Work

Heart Rate (bpm)

Oxygen Uptake (ml/kg/min)
Burning Calories thru Exercise

- Compendium of Physical Activity
  - Estimates Calories expended for AB Activities
  - Includes Mobility & ADLs
- VA Cooperative Study
  - EE in SCI for 50 activities
  - Estimates for caloric expenditure
- Aerobic Exercise Benefits
- Resistance Exercise Benefits

<table>
<thead>
<tr>
<th>Exercise Description</th>
<th># Minutes</th>
<th>Cal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobics</td>
<td>30</td>
<td>297</td>
</tr>
<tr>
<td>Walking</td>
<td>60</td>
<td>276</td>
</tr>
<tr>
<td>Swimming</td>
<td>30</td>
<td>203</td>
</tr>
<tr>
<td>Bicycling</td>
<td>30</td>
<td>237</td>
</tr>
<tr>
<td>Aerobics</td>
<td>30</td>
<td>274</td>
</tr>
<tr>
<td>Aerobics</td>
<td>30</td>
<td>265</td>
</tr>
<tr>
<td>Swimming</td>
<td>30</td>
<td>205</td>
</tr>
<tr>
<td>Swimming</td>
<td>15</td>
<td>55</td>
</tr>
<tr>
<td>Walking</td>
<td>60</td>
<td>271</td>
</tr>
<tr>
<td>Walking</td>
<td>30</td>
<td>181</td>
</tr>
</tbody>
</table>
SCI Physical Activities

- Collins et al, 2010
  - N=170 veterans with C5-L4 SCI
  - 27 Physical Activities
  - 1 SCI MET=2.7 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\) O\(_2\)
  - Example: Wheeling
    - C5-C8: 7.7 1.4 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\)
    - T1-T8: 8.0 1.7 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\)
    - T9-L4: 11.3 4.4 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\)

<table>
<thead>
<tr>
<th><strong>Mode</strong></th>
<th><strong>Cardiovascular</strong></th>
<th><strong>Strength / Power</strong></th>
<th><strong>Flexibility</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arm Crank Ergometry</td>
<td>Therabands</td>
<td>Active Assist:</td>
</tr>
<tr>
<td></td>
<td>Wheelchair Ergometry</td>
<td>Wrist Weights</td>
<td>- Anterior Shoulder</td>
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<tr>
<td></td>
<td>Arm Crank Cycling</td>
<td>Body Weight</td>
<td>- Pectoral Muscles</td>
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<tr>
<td></td>
<td>Community Wheeling</td>
<td>Dumbbells &amp; Free Weights</td>
<td>- Rotator Cuff</td>
</tr>
<tr>
<td></td>
<td>Seated Aerobics</td>
<td>WC Accessible Machines</td>
<td>Passive Assist</td>
</tr>
<tr>
<td></td>
<td>Aquatics</td>
<td>FES-Iso kinet ic</td>
<td>- Hip Flexors</td>
</tr>
<tr>
<td></td>
<td>Wheelchair Recreation</td>
<td></td>
<td>- Knee Flexors</td>
</tr>
<tr>
<td></td>
<td>FES-LCE</td>
<td></td>
<td>- Plantar Flexors</td>
</tr>
<tr>
<td></td>
<td>ACE &amp; FES-LCE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Frequency</strong></th>
<th>3-7 days/week</th>
<th>1-3 Sets, 2-3 days/week;</th>
<th>7 days/week</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intensity</strong></td>
<td>RPE 11-13, 50-85% VO₂Peak, PO₂Peak, or HR₉₀ Reserve, 60-90% HR₉₀ Peak, 3-5 word sentences</td>
<td>8-12 reps at 60-75% 1 RM</td>
<td>As tolerated</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>20 to 60 minutes; continuous or interval</td>
<td>30-60 minutes</td>
<td>5-15 minutes</td>
</tr>
<tr>
<td><strong>Progression</strong></td>
<td>Slow (&lt;5%/week)</td>
<td>Increase resistance when 12 reps achieved</td>
<td>Work to increase ROM as tolerated</td>
</tr>
<tr>
<td><strong>Precautions</strong></td>
<td>Avoid exertional hypotension, May initially require multiple sets of 5-10 minute duration, Monitor for autonomic dysreflexia, Avoid thermal stress, Include warm-up &amp; cool-down</td>
<td>Avoid valsalva maneuver, Provide spotter, Seatbelt &amp; Chest strap for balance, Adaptive grip &amp; mitts, Don’t exceed stress limits of wheelchair</td>
<td>Stretch to strain, not pain, Avoid valsalva maneuver, Don’t overstress insensate joints, Provide midshaft support for long osteopenic limbs</td>
</tr>
</tbody>
</table>
Exercise for SCI?

- “I'm sorry. My responses are limited. You must ask the right questions.”
  - Is it possible to achieve negative energy balance after SCI?

- “That, Detective, is the right question.”
  - Dr. Alfred Lanning to Det. Dell Spooner
Exercise Rx for Fat Loss

- Limitations: Ortho, Medical, Time, and Goals
- Mode: Wt-bear vs. Non-Wt-Bearing
- Frequency: 3-5x/week
- Intensity: 55-90% HR_{Max}
- Duration: 20-60 minutes
- Progression: Initial vs. Maintenance

- ACSM (2005): Mild-moderate activity, 300-400Kcal/d or >2000kcal/wk
- DGA (2005): 60 min/day Maintenance
  90 minutes/day Weight Loss

ACSM: American College of Sports Medicine
DGA: Dietary Guidelines for Americans, USDA
Exercise to Reduce Obesity in SCI: RR&D B3918R
Glucose Transporters

Non-Insulin-Mediated Glucose Transport

AMP Kinase

PI 3-Kinase

GLUT4 Transcription

GLUT4i

GLUT4A

EXERCISE

↑AMP:ATP
↑CR:PCr
Exercise Training Study

- 3 Year Interventional Study
  - Randomized, Baseline Controlled Prospective
  - Impact of 16 weeks aerobic exercise (60’ 5 d/wk x 16 wks)
- T4-L2 Motor Complete Paraplegia (n=24)

Outcome Measures
- Primary Variables
  - % Body Fat
  - Insulin Sensitivity & Glucose Effectiveness
  - \( VO_{2\text{Peak}} \)
- Secondary Variables
  - Lipid Profiles
  - LE BMD
  - Psychosocial Outcomes
Intervention: ACE vs FES LCE

- **Group Assignment**
  - ACE (n=12)
  - FES LCE (n=12)

- **Arm Crank Ergometry**
  - Time: 60 Minutes/day
    - 10’ Warm Up
    - HR Zone: 40 minutes/day
    - 10’ Cool Down
  - Intensity: 70% $HR_{peak}$
  - Frequency: 5x/week
  - Duration: 16 weeks
    - Including 4-Week Adaptation

- **Dismissal**
  - 6 sessions missed
Resting Blood Pressure

FES vs. ACE Blood Pressure

Blood Pressure (mm Hg)

Pre  Post

FES Mean SBP
FES Mean DBP
ACE Mean SBP
ACE Mean DBP
Cholesterol (Total & HDL-c)

**FES vs. ACE Cholesterol**

Cholesterol (mg/dL)

- **Pre**
  - FES Mean Total Chol
  - FES Mean HDLC
  - ACE Mean Total Chol
  - ACE Mean HDLC

- **Post**
  - FES Mean Total Chol
  - FES Mean HDLC
  - ACE Mean Total Chol
  - ACE Mean HDLC
Percent Body Fat

FES vs. ACE Percent Body Fat

Pre | Post

FES Mean | ACE Mean
Fat Free Mass (kg)

FES vs. ACE Fat-Free Mass

- FES Mean
- ACE Mean
Energy Expenditure / Session

Energy Expenditure / Workout

Kcals/Session

FES Mean
ACE Mean

Ride 1
Ride 40
Ride 80
Anaerobic Exercise for ↑ FFB

- Limitations: Ortho, Medical, Time, Goals
- Mode: Free Weight vs Machine
  - Isometric
  - Isotonic
  - Isokinetic
- Frequency: 2-4x/wk
- Intensity: >65% 1RM
  - Repetitions: 1-10
  - Sets: 3-6
- Recovery: 2-3 minutes/set
- Periodization
Physical Barriers Remain

- Exercise Specialists
  - Few Knowledgeable about SCI
  - Guidelines Incomplete

- Fitness Facilities
  - Often lack parking, equipment access, full restroom access, or customer service desks of appropriate height

  - Figoni et al, 1998;
  - Rimmer et al, 2000
  - Odette et al, 2003
Objective 5

- Discuss potential risks & benefits of bariatric surgical options for persons with SCI
Bariatric Surgery
Bariatric Surgery after SCI

- Morbidly Obese man with paraplegia
  - 51 y.o. man with T7 AIS A paraplegia & BMI 48.6 kg/m² (6’2” x 373#)
  - Metabolic Syndrome (DM2, HTN, Dyslipidemia, Obesity) GERD and OSA
  - Roux-en-Y gastric bypass

- 12-month Weight Loss of 52 kg
  - BMI ↓ to 33 kg/m²
  - HgbA1c ↓ 10.3 to 5.9 mg%
    - Stopped oral hypoglycemic
  - Cholesterol from 106 to 112 mg%
  - HDL-c ↑ from 47 to 57 mg%
  - HTN improved
  - OSA & GERD resolved
  - Improvements maintained at 21 months post-operatively

Cost / Benefit Bariatric Surgery Comparison

- Risk Reduction
  - OA, OSA, CAD, DM, HTN, Dyslipidemia, Gout, USI

- Risks in SCI
  - Usual Surgical Risks
  - Autonomic Dysreflexia
  - Spasticity
  - Dumping Syndrome
  - Bowel Incontinence
Summary

- Obesity is underappreciated in SCI
  - Epidemic proportions
- Central mediator of the Metabolic Syndrome
  - Central Obesity
  - Dyslipidemia
    - High Triglycerides
    - Low HDL-cholesterol
  - Hypertension
  - Insulin Resistance
- Treatment Options
  - Behavior Modification
  - Pharmacological
Acknowledgements

- VA Research Career Development Award
- EPVA Scholar Award
- VA RR&D B3307R
- VA RR&D B3155R
- VA RR&D B3918R
- VA HSR&D
- NIH NCRR K23 Mentored Clinical Research
- NIDRR Model SCI System Grant H133N000009
- NIDRR H133G040274
- NIH NCRR General Clinical Research Grant
- PVA SCRF Grant
Bibliography

Bibliography (Continued)


