Biomechanics of Skeletal Muscle and the Musculoskeletal System

Hamill & Knutzen (Ch 3)
Nordin & Frankel (Ch 5), or Hall (Ch. 6)

Muscle Properties

- **Irritability**
  - Muscle has the capability of receiving and responding to various stimuli.

- **Contractility (unique)**
  - When a stimulus is received, the muscle has the capability of shortening (by as much as 50-70% [average 57%]).
Muscle Properties (cont.)

- **Extensibility**
  - Muscle has the characteristic of being able to lengthen, either when it is in a passive (partner aided stretches) or active state (eccentric contractions).

- **Elasticity**
  - Whenever a muscle has been shortened or lengthened, it has the ability to return to its normal or resting length and shape.

Functions of Muscle

- **Produce Movement**
- **Maintain Postures and Positions**
- **Stabilize Joints**
- **Other Functions (not related to movement)**
  - Support and protect visceral organs
  - Alter and control pressures within cavities
  - Help in maintenance of body temperature
  - Control entrances and exits to the body

Factors Influencing the Production of Muscular Tension

- Muscle Size (cross-sectional area)
- Electro-mechanical delay
- Recruitment, Frequency, Synchronization (activation level)
- Length-Tension Relationship
- Velocity-Tension Relationship (Muscular Power)

Factors Influencing the Production of Muscular Tension

- Prior Contraction History
- Elastic Elastic Energy (storage and recoil)
- Muscle Temperature
- Muscle Fibre Type
- Angle of pennation
Muscle Cross Sectional Area

Hypertrophy - an increase in the size of a tissue such as muscle.
Hyperplasia - an increase in number of muscle fibers

Strength vs Cross-Sectional Area

Electromechanical Delay

Stimulus Response of Muscle
Muscle Force-Time Profile

Force (Tension) Length Relationship for Human Skeletal Muscle

- We can look at two length-tension relationships.
- The next few slides show this relationship for isolated muscle preparations. This is where the muscle has been taken from some poor unsuspecting frog (or other animal model) and then stimulated at a FULL range of lengths. In these experiments as much of the passive structures (tendon, perimysium, etc.) as possible is cut away.
- We can also look at the relationship for intact muscle that include the tendon and connective tissue.

Redrawn from Ralston et al., 1947.
Total Length-Tension Curve

Qualitative graph of previous slide showing experimental data

Contractile Length

Brachialis
Biceps
Brachioradialis

Concentric
Eccentric

Data from Edman, 1988.

CC Force-Velocity Curve

All of the previous graphs have shown force-length and force velocity at maximum activation levels
3-D Plot
Force – Length - Velocity

Power

\[ \text{Power} = \text{Force} \times \text{Velocity} \]

Maximum power occurs at about 30-33% of maximal velocity of shortening and about the same percentage of maximum concentric force.

Optimal Power

Athletes must find as high a level of power output as possible that can be sustained for the duration of their event.
Muscular Torque Production

- We have looked at several biomechanical factors that affect muscular FORCE production.
- We now need to review additional factors that affect the muscle TORQUE produced at a joint.

**Forearm Flexion**

*Torque vs. Forearm Flexion Angle*

Redrawn from Edgerton et al., 1986.
Force-Length Curve of Muscle

Approximate Physiological Range

Tension

Lo
Length of Contractile element

Torque ≠ Force

Force is equal
......but

......moment arms
are very different
### Factors Affecting Muscle Torque

#### FORCE
- force-length curve
- force - velocity curve
- activation profile
- prior contraction history
- angle of pennation
- freq., temp., etc.

#### FORCE ARM
- insertion point
- line of action of muscle and joint angle
  (i.e. force x force arm)

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#### Isometric Exercise (static contraction)

#### Isotonic Exercise (constant resistance)

- Concentric Contraction
- Eccentric Contraction
**Constant weight ≠ constant resistance**

- In a free weight exercise once you have got the weight moving you will require less force to continue it.
- Furthermore to control the weight at the later stages of the lift you will have to all the weight to decelerate, hence your limbs will decelerate.
- How can we use the knowledge of muscle mechanics to better train muscles?
- Muscle strength at various angles
- Inertial resistance of free weights?

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**Variable Resistance**

(leverage \{force \times distance\})

![Diagram of variable resistance](Redrawn from Smith, 1982.)

**Max torque**
- Barbell ▲
- Nautilus ○

![Graph of muscle torque vs. elbow angle](Redrawn from Smith, 1982.)
Adding Resistance with Chains

This system allows a gradual increase in resistance which will reduce the amount of deceleration that occurs later in the lift.

This system combines the benefits of free weights with the benefits of variable resistance.

Pulleys

- Simple pulleys are designed to change the direction of force.
- In this case the weight stack moves up when the subject pushes out horizontally.

Type 1 Pulley
(no increased mechanical advantage)
**Moveable Pulley**

Moveable pulleys are not that relevant to Kin201 material – except possibly in an ergonomic design of a workplace.

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**Type 1 Round Pulley**

Changing direction of force application, it does not change the mechanical advantage $MA = 1$.

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**Seated Row**

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**Dumbbell Row**

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**Barbell Bent-Over Row**

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**Type 2 or compound pulley**

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Figure 5.17 • Type 2 pulley.
**Strength Tests**

- Any muscular strength or endurance test that is carried out on a machine should always be repeated on the same machine (or same make) so that any leverage differences between weight machines do not influence the results.
- Similarly, if comparing to a database so as to classify your client's results you MUST be aware of what equipment was used when compiling the database results.

**Pulleys in the Human Body**

- There are no true pulleys in the human body.
- However, there are many examples of grooves in bones, tendinous straps and cartilaginous/bone tunnels that allow for change in direction of the muscle pull.

**Change of Direction of Muscle Force (Muscle Pull)**

Figure 5.19 • Examples of pulley in body: (A) Finger flexion, (B) Peroneus longus and cuboid.

**Extreme Wrist Extension**

Kin 380 & Kin 481

Prolonged wrist extension is believed to be a significant risk factor for carpal tunnel syndrome (Rempel 1991).
Isokinetic Concentric

Isokinetic machines are designed so that the resistance is due to fluid viscosity.

**Additional Factors in Muscular Force Production**

**Twitch Response**

- Fast Twitch (FT) Fibre
- Slow Twitch (ST) Fibre

**Muscle Temperature**

- Normal body temperature
- Elevated body temperature

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Figure 6.43 The resultant force exerted by tendon on adjacent wrist structures as a function of wrist angle and tendon load. Resultant force is independent of tendon and wrist size (from Armstrong and Chaffin, 1979).
Warm Up – more than biomechanical

- Decreased viscosity of blood
- Enables oxygen in the blood to be delivered at greater speed and volume
- Increase of temperature in the muscles
- Facilitates enzyme activity
- Encourages the dissociation of oxygen from haemoglobin
- Decreased viscosity within the muscle
- Greater extensibility and elasticity of muscle fibres and associated connective tissue
- Increased force and speed of contraction

Muscle Architecture and Angle of Pennation

Physiological Cross-Section Area (PCSA)
Other Mechanical Factors

- Tendon Length
- Joint Stability
- The role of two joint muscles

\[ F_{\text{tendon}} = F_{\text{fibres}} \times \cos 30 \]
Joint Stability

Dislocating Component

Rotary Component

Non-Rotary Component

Stabilizing Component

Two-Joint Muscles

Disadvantages
- Cannot shorten enough to produce full range of motion at both joints.
- Cannot stretch enough to produce full range of motion in opposite direction at both joints.

Advantages
- Length and velocity optimization
- Reduction of work required from one-joint muscles (save energy)

Brachioradialis

Origin: Humerous - Lateral Condyle
Insertion: Radius (Lateral Distal) - Styloid Process

Antagonist Muscle Action

- Which muscles are active during a squat exercise (which requires hip and knee extension)?
- Gluteus maximus, quadriceps and hamstrings.
- Is this a contradiction as the hamstrings flex the knee?
- No… due to difference in moment arms.
- Lombard’s Paradox
- At the hip, the moment arm of rectus femoris is much smaller than hamstring moment arm so hip extension is not reduced.
- Similarly at the knee the quadriceps moment arm is greater than the hamstrings, so the knee extends.
To Squat or Not to Squat? Biomechanics of the Knee

Patellofemoral joint reaction force \((P)\) is formed by the vector sum of the force vector of the quadriceps tendon \((F_Q)\) and the force vector of the patellar tendon \((F_P)\).

There is a question regarding patello-femoral compressive force in the Simple Biomechanical Models question set.
**Full Squat**
Crease at hip (a) is below knee. So thighs tend to just break below parallel.

**Seated Knee Extension**

- **Force on Tibial Tuberosity**: Pelvis tends to rotate back furthering the relaxation of the hamstrings.
- **Shearing component**: If the hamstrings do not forcefully contract, the dominant quadriceps force acting on the knee will create considerable shear (red vector component).

**Definitions**
- **Prime Movers or Target Muscle**: Muscle(s) primarily responsible for the movement.
- **Synergists or Assistors**: Muscles that assist the prime mover.
- **Dynamic Stabilizers**: Muscles stabilizing the limbs moving (typically these are two joint muscles that would be lengthening across one joint and shortening across the other (therefore the net result is little change in length)).
- **Stabilizers**: Muscles that stabilise adjacent body segments or contract with no appreciable movement.
So in the full squat, the hamstrings and gastrocnemius act as dynamic stabilizers as the predominant torques from the gluteus maximus, quadriceps and soleus produce the movement.

**Figure 6.20** Ratio of patellar tendon force ($F_p$) to quadriceps tendon force ($F_q$) as a function of flexion angle.
Adapted from Hayes, Stone, & Shybut 1984.

**Figure 6.21** Patellofemoral contact areas as a function of change in degree of knee flexion. As the knee is flexed from full extension (0°) through 90°, the contact area migrates from the inferior retropatellar surface to the superior region. At 135° of flexion, the contact area is on both the superolateral surface and the medial odd facet.
From “Biomechanics of the patellofemoral joint” by D.S. Hungerford & M. Barry, 1979, Clinical Orthopaedics and Related Research, 144 (Fig. 2, p. 11). Copyright 1979 by Lippincott-Raven. Adapted by permission.
Knee Ligament Function

Figure 6.22. Patellofemoral contact area, pressure, and force vary with knee flexion angle. Adapted from Huberti & Hayes 1984.

Anterior Cruciate Ligament Injury

Figure 6.16. (a) Anterior cruciate ligament (ACL) injury caused by a backward fall. This mechanism forcibly pushes the tibia anteriorly relative to the femur and stretches the ACL. (b) Anterior cruciate ligament injury caused by the "phantom foot" provided by the section of ski posterior to the boot.

Posterior Cruciate Ligament Injury

Figure 6.17. Mechanism of posterior cruciate ligament injury. (a) Knee velocity collision on which injury with the knee flexion 90° from full extension. (b) Ligament rupture due to pushing away posteriorly. (c) Resulting stress on the ligament, causing fibrocartilage tear or a chronically altered knee.