Mechanical Principles in Orthodontic Force Control

Two Types of Orthodontic Appliances: Removable vs. Fixed

Fixed appliances
- Bands
- Brackets
- Wires
- Accessory appliances

Brackets
- Metal bracket
- 24K plating gold bracket

Brackets
- Clear Bracket
Plastic brackets

- Staining and discoloration
- Poor dimensional stability
- Larger friction

Ceramic brackets

- Advantages over plastic brackets:
  - Durable, resist staining
  - Can be custom-molded
  - Dimensionally stable
- Disadvantages over metal brackets:
  - Bulkier than metal bracket
  - Fractures of brackets
  - Friction is bigger than that in metal bracket
  - Wear on teeth contacting a bracket
  - Enamel damage on debonding

- Metal-reinforced ceramic bracket

Self ligating bracket

"Smart" Clips
Invisible orthodontics?

- Lingual brackets
- Invisalign

Step 5: You've finished treatment!
Step 4: You wear your aligners.
Step 3: You receive your aligners in a few weeks.
Step 2: Invisalign® makes your aligners.
Step 1: Visit your orthodontist or dentist.
Clear aligner therapy (CAT) applicability

CAT performs well:
- Mild-moderate crowding with IPR or expansion
- Posterior dental expansion
- Close mild-moderate spacing
- Absolute intrusion (1 or 2 teeth only)
- Lower incisor extraction for severe crowding
- Tip molar distally

CAT does not perform well:
- Dental expansion for blocked-out teeth
- Extrusion of incisors*
- High canines
- Severe rotations (particularly of round teeth)
- Leveling by relative intrusion
- Molar uprighting (any teeth with large undercuts)
- Translation of molars*
- Closure of premolar extraction spaces*

Fig 11-16

0.1-0.5 mm in thickness

Invisalign vs. braces

- Patients treated with Invisalign relapsed more than those treated with conventional fixed appliances.

Wires

- Type:
  - NiTi wire (Nickel-Titanium wire)
  - TMA wires (Titanium-Molybdenum-Alloy)
  - Stainless steel wire
- Shape
  - Round wire
  - Rectangular wire
**General Characteristics of Orthodontic Forces**

- Optimal: light, continuous
  - Ideal material
  - Maintains elasticity
  - Maintains force over a range of tooth movement

**Materials & Production of Orthodontic Force**

- Elastic behavior
  - Defined by stress-strain response to external load
  - Stress = internal distribution of the load; force/unit area
  - Strain = internal distortion produced by the load; deflection/unit length

**Orthodontic Model: Beam**

- Force applied to a beam = stress
- Measure deflection = strain; examples:
  - Bending
  - Twisting
  - Change in length

**Beam Properties in Orthodontics**

- Defined in force deflection or stress-strain diagrams
- Useful properties:
  - Stiffness
  - Range, springback
  - Strength
Bending Properties of an Orthodontic Wire

Defined by 3 points

1. Proportional limit
   - Point at which permanent deformation is first observed
   - Similar to "elastic limit"
2. Yield strength
   - Point at which 0.1% deformation occurs
3. Ultimate tensile (yield) strength
   - Maximum load wire can sustain

Stiffness of an Orthodontic Wire

Modulus of elasticity (E)
- Young’s modulus
- Stiffness below proportional limit
- Slope of load-deflection curve
- Stiffness $\alpha$ E
- Springiness $\frac{1}{E}$

Stiffness versus Springiness

- Reciprocal relationship
  - Springiness = $\frac{1}{\text{stiffness}}$
- Related to elastic portion of force-deflection curve (slope)
  - More horizontal = greater springiness
  - More vertical = stiffer

Range versus Springback

- Range
  - Distance wire will bend elastically before permanent deformation
- Springback
  - Found after wire deflected beyond its yield point
  - Clinically useful
    - Wires often deflected past yield point

Relationship of Strength, Stiffness & Range

- Strength = stiffness x range

Resilience, Formability

- Resilience
  - Area under stress-strain curve to proportional limit
  - Represents energy storage capacity
- Formability
  - The amount of permanent deformation a wire can withstand before breaking
Ideal Orthodontic Wire Material

- Deflection properties:
  - High strength
  - Low stiffness (usually)
  - High range
  - High formability
- Other properties:
  - Weldable, solderable
  - Reasonable cost
- No one wire meets all criteria!
  - Select for purpose required

Wire Materials

- Precious metal alloys
  - Before 1950’s: gold alloys, corrosion resistant
- Stainless steel, cobalt-chromium (elgiloy®) alloys
  - Improved strength, springiness
  - Corrosion resistant: chromium
    - Typical: 18% chromium, 8% nickel
- Nickel-titanium (NiTi) alloys
  - 1970’s applied to orthodontics
  - Demonstrates exceptional springiness
    - Two special properties: shape memory, superelasticity

Austenitic NiTi (A-NiTi)

- Introduced 1980’s
  - Demonstrate superelasticity
    - Large reversible strains
      - Over wide range of deflection, force nearly constant
      - Very desirable characteristic
    - Non-elastic stress-strain (force deflection) curve
      - E.g., Chinese Ni-Ti

Uses of Ni-Ti Arch wires

- Good choice:
  - Initial stages of Tx
  - Leveling and aligning (good stiffness, range)
- Poor choice:
  - Finishing (poor formability)

Elastic Properties: Effects of Size and Shape

- Wire properties
  - Significantly affected by wire (beam) cross section and length
    - Magnitude of change varies with wire material
    - Similar proportional changes among wire materials

6 weeks later
Elastic Properties: Effects of Size and Shape

- **Effects of Diameter: Cantilever**
  - **Strength**
    - Changes to third power
    - Ratio between larger to smaller beam
    - E.g., double diameter: deliver 8x strength
  - **Springiness**
    - Changes to fourth power
    - Ratio between smaller to larger beam
    - E.g., double diameter: wire 1/16 as springy

- **Effects of Length (Cantilever)**
  - **Strength**
    - Decreases proportionately
    - E.g., double length: half the strength
  - **Springiness**
    - Increase by cube of ratio
    - E.g., double length: 8x the springiness
  - **Range**
    - Increases by square of ratio
    - E.g., double length: 4x the range

**Spring Design**

- Requires appropriate balance:
  - Heavy wire:
    - High strength, high force, low range
  - Light wire:
    - Low strength, low force, high range
- Example: removable appliance
  - Finger spring
  - High strength needed to avoid deformation
  - Force can be reduced by increasing wire length
  - Add helix

**Biomechanical Design Factors in Orthodontic Appliances**

- **Terms:**
  - Force (F): load applied to object that will tend to move it to a different position in space
    - Units: grams, ounces
  - Center of resistance (C_R): point at which resistance to movement can be concentrated
    - Object in free space: C_R=center of mass
    - Tooth root: C_R=halfway between root apex and crest of alveolar bone
Design Factors in Orthodontic Appliances

- **Moment**: product of force times the perpendicular distance from the point of force application to the center of resistance
  - Units: gm-mm
  - Created when line of action of a force does not pass through the center of resistance
    - Force will translate and tend to rotate object around center of resistance

- **Couple**: two forces equal in magnitude but opposite in direction
  - No translation
  - Produces pure rotation around center of resistance

Friction

- Can dramatically affect the rate of tooth movement
- Considerations:
  1. Contact angle between orthodontic bracket and arch wire
  2. Arch wire material
  3. Bracket material

Friction and Tooth Movement

- Effects of arch wire material
  - The greater titanium content, the more friction
    - Due to surface reactivity (chemistry)
  - Sliding resistance: titanium > stainless steel arch wires

Contact Angle

- When sliding a tooth on an archwire:
  - Tooth tips
  - Further tipping prevented by moment created as bracket contacts wire = contact angle
    - Increase contact angle = increase resistance
    - Greater force needed to overcome friction
Tooth Movement
• Effects of bracket material
  – Stainless steel: least friction
  – Titanium brackets: high friction likely
  – Ceramic:
    • Rough, hard surface
    • Increases friction
  – Ceramic with steel slot
    • Reduced friction

Alternatives to Sliding (Friction)
Segmented mechanics or closing loops mechanics
• Activate loops
• Loops close to original shape
• Retract teeth toward space as loops close
• No sliding, no friction
• “Frictionless” mechanics

Summary
• Ideal orthodontic forces
• Wire properties
  – Strength, stiffness, range (springback)
  – Resilience, formability
• Wire materials
• Changes in diameter, length
• Design factors
  – Force, center of resistance, moments, couples, center of rotation
  – Use of rectangular wires: couples
• Friction
  – Contact angle, wires, brackets