Wheelchair Components

(1) Seating System

Dimensions:
(1) seat width – adult standard 18” or 16”
(2) seat depth – adult standard 16”
(3) back height - adult standard 15-17”
(4) seat to floor height – standard 18-20”

(2) Seat Cushion – Adds 2” or more to seat to floor height

(3) Armrests
   o Desk length
   o Full length

(4) Leg rests – 60, 70, 90-degree bend

(5) Foot plates – Flip-up or rigid

(6) Rear wheels – standard 24” diameter

Tires
   • Solid rubber (as in depot or lobby chair)
   • Pneumatic
   • Foam filled
   • High pressure

Wheels
   • Spoked wheels
   • Mag wheels
(7) **Hand rims** – metal or plastic coated

(8) **Rear Wheel Axle** – Position relative to COG; Adjustability

(9) **Camber adjustment**

(10) **Casters and caster forks** – caster diameter 2” – 8”

(11) **Wheel locks**

(12) **Hill holders**

(13) **Anti-tipper bars**
Types of Manual Wheelchairs

Standard and Light weight Wheelchairs

(1) Standard folding wheelchair “Depot chair”
   Frame: Folding with cross bars; Chrome plated, cold-rolled steel; 40-50 lbs.
   Function: ↑ Resistance with self-propulsion, ↑ Turning radius, Heavy to lift

(2) Light weight standard wheelchair
   Frame: Folding crossbars; Carbon steel (most common w/c material); 30-40 lbs.
   Function: ↓ Resistance for self-propulsion, Lighter for caregiver to push/lift

(3) Reclining Seating System
   Frame: Folding with crosses bars; Elevating leg rests; Standard or light weight material
   Function: Used for individuals who are unable to sit upright (e.g. hip flexion restrictions, orthostatic hypotension); Inefficient for self propulsion; Large turning radius

(4) Tilt-in-Space Seating System
   Frame: Usually non-folding; Carbon steel material; The seat to back angle is set at a constant angle and the entire seating system will tilt 0-45 degrees.
   Function: The user is usually unable to self-propel; Provides support for poor trunk and head control and pressure relief.

(5) Hemi-Height Wheelchair
   Frame: Light weight standard wheelchair with a low seat to floor height; Often has smaller rear wheels than standard wheelchairs
   Function: Often used by hemiplegic patients; Users propel with one arm and steer with one foot or the patient propels with both feet.

(6) One Arm Drive
   Frame: Usually non-folding; Axles are linked so that both wheels are operated from one side.
   Function: Operation (propelling and steering) can be done with a single arm. The user has one functional UE with the LE’s unable to assist
**Ultralight Wheelchairs**

<table>
<thead>
<tr>
<th>Features of ultralight wheelchairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adjustable axle position (up/down, fore/aft)</td>
</tr>
<tr>
<td>• ± 20 lbs.</td>
</tr>
<tr>
<td>• Rigid or folding frame</td>
</tr>
<tr>
<td>• Lighter than standard or light weight w/c</td>
</tr>
<tr>
<td>• Material: Chrome-moly steel, aluminum-carbon composite or titanium (lightest)</td>
</tr>
<tr>
<td>• Quick release wheels</td>
</tr>
</tbody>
</table>

(1) **Folding Frame Ultralight Wheelchair**

Frame: Folding with cross bars

Function: ↓ Resistance for self-propulsion; ↓ Turning radius; ↓ weight for Lifting (car transfers); Less efficient propulsion than rigid frame (frame flexes → energy loss);

(2) **Rigid Frame Ultralight Wheelchair**

Frame: No cross bars; Folds into shape of a box

Functions: ↓ Resistance for self-propulsion; ↓ Turning radius; ↓ weight for Lifting (car transfers); More efficient propulsion than than frame (No flex in frame → ↓ energy loss during propulsion)

**Sports Wheelchairs**

<table>
<thead>
<tr>
<th>Features of Sport Wheelchairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rigid frame</td>
</tr>
<tr>
<td>• 5-20 lbs.</td>
</tr>
<tr>
<td>• Designed for specific sport (e.g. rugby, tennis, basketball)</td>
</tr>
<tr>
<td>• ↑ camber of rear wheels (↑ lateral stability and lower COG)</td>
</tr>
</tbody>
</table>
Wheelchair Propulsion

Kinematics

**Propulsion cycle:** The start of the push phase to the end of the recovery phase.

**Push Phase:** The hand makes contact with the push rim and then applies a propulsive force. The push phase makes up approximately 25% of the total cycle in a standard w/c, 35% in an ultralight w/c, and 33-37% in a racing w/c.

In the early part of the push phase, the hand is accelerating to the speed of the rim. A propulsive force is then applied through the hand rim creating a torque about the wheel axle.

**Recovery Phase:** The hands disengage from the push rim and return to initiate the next push phase. The recovery phase is about 65-75% of the propulsion cycle.

**Push angle:** The number of degrees that the hand applies a propulsive force on the hand rim, creating a torque about the wheel axle.

**Peak torque:** Observed 30-40% into the push phase, regardless of seat position

**Stroke rate:** Propulsion cycles per minute

**Propulsion patterns** (Boninger et.al. 2002):

- Semicircular:

- Single looping over propulsion:

- Double Looping Over Propulsion:

- Arc:

**Effect of seat position on the propulsion cycle:**

- High seat relative to wheel → Shorter push phase
- Lower seat relative to wheel → Longer stroke
**Wheelchair Propulsion (cont.)**

**Muscle Activity**

**Push Phase:**
- **Biceps**: Active early push
- **Anterior deltoid**: Active throughout push
- **Triceps**: Active mid to late push
- **Flexor Carpi Ulnaris**: Active throughout push
- **Extensor Carpi Radialis**: Active throughout push
- **Pectoralis**: Active throughout push
- **Trunk flexors**: Increase with effort

**Recovery Phase:**
- **Posterior deltoid**: Active throughout recovery
- **Triceps**: Active early recovery

**Changes in muscle activity with fatigue:**
- Biceps fire prior to hand rim contact (late recovery phase)
- FCU fires earlier in push phase

**Changes in muscle activity depending on w/ set-up (positioning):**
**Joint motion and forces during Wheelchair Propulsion**

**Shoulder:** The highest joint moments and power values in the upper extremity occur at the shoulder. Peak hub torque occurs from 15° shoulder extension $\rightarrow$ 15° shoulder flexion, during the push phase.

**Elbow:** Peak hub torque occurs from 100° elbow flexion $\rightarrow$ 80° elbow flexion

**Wrists:** The highest joint reaction forces occur at the wrist during propulsion. These joint reaction forces increase with fatigue.

**Trunk:** Trunk extension and flexion will change on inclines. Speed of propulsion may influence trunk motion. Trunk flexion often increases with fatigue.

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**Factors Influencing Wheelchair Performance**

**Rolling resistance: Influence of w/c and surface on RR**

**Rolling Resistance (RR):** The combined drag created by casters, tires and bearings. It stays constant whatever the speed of the wheelchair. Rolling resistance determines the energy required to propel a wheelchair up to about 2 meters/sec., at which point air resistance plays an increasingly significant role.

(1) **Rolling Surface**

\[
\downarrow \text{RR} \quad \text{Flat, hard and smooth surfaces} \\
\uparrow \text{RR} \quad \text{Rough, uneven and soft surfaces (carpet, grass, sand)}
\]

Tight woven carpet is 2x RR of hard surface
Shag carpet is 5x RR of hard surface

(2) **Weight Distribution**

- **Standard w/c configuration:**
  - 60% Rear wheel
  - 40% Front casters

- **COG Posterior in w/c:**
  - 75% Rear wheel
  - (move seat back or axle forward) 25% front casters

$\rightarrow$ If all other factors remain constant, RR is reduced by 6% with COG posterior
Rolling resistance (cont.)

3) Tires
   • Conventional pneumatics (65 psi): Less RR than solid or semisolid tires
   • High Pressure pneumatics (100-160 psi); 25-30% less RR than conventional
     (** ↓ RR on smooth surfaces)
     (** ↑ RR on soft surfaces)
   • Foam Insert – solid insert replacing air tube: RR is 15-20% higher than
     conventional pneumatics
   • All terrain tires ↑ RR on hard surfaces
     ↓ RR on soft surface

   ** Narrow, high pressure tires will have higher RR on soft terrain
   ** Treaded tires will improve traction for wheeling and braking

4) Rear Wheel Size (standard 24”): Larger wheels have lower RR and roll over surface
   irregularities more easily. Racing chairs often have 27” wheels.

5) Rear Wheel Camber: RR reduces with more than 10° of camber, while less than 10°
   has minimal effect on RR.

<table>
<thead>
<tr>
<th>Advantages to camber</th>
<th>Disadvantages to camber</th>
</tr>
</thead>
<tbody>
<tr>
<td>↓ COG</td>
<td>Lowers seat to floor height → transfers more difficult.</td>
</tr>
<tr>
<td>↑ Lateral stability</td>
<td>Too wide for doors</td>
</tr>
<tr>
<td>↑ Propulsion efficiency</td>
<td>Narrow seat width</td>
</tr>
<tr>
<td>↓ Downward turning tendency</td>
<td></td>
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<tr>
<td>Protects hands in tight spaces</td>
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</tbody>
</table>

6) Rear wheel Toe-in or Toe-out and caster angle:
   Significant increase in RR if rear wheels are not aligned.
   It the caster stem is not vertical → flutter → ↑ RR
**COG relative to rear axle: Impact on w/c performance**

(1) **Seat Height**

**Optimal seat height for efficient propulsion**: Elbow flexed 120° when hand hits highest point of rim

**Conventional seat height**: Elbow flexed 60 - 80° when hand hits highest point of rim.

<table>
<thead>
<tr>
<th>Higher seat</th>
<th>Shorter propulsion stroke (push phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower seat</td>
<td>Longer propulsion stroke</td>
</tr>
</tbody>
</table>

Other considerations:
- Transfers
- Environment
- Functional goals

(2) **Horizontal Center of Gravity Position (fore-aft)**

* The closer the COG is to the rear axles, the greater effect the rear wheels have on performance.

**Optimal position for efficient propulsion**: The shoulder axis is ≥ 2” posterior to the rear axle.

**Conventional positioning (standard w/c)**: Shoulder axis is 1-2” anterior to the rear axle.

**Optimal positioning for a w/c athlete**
- The shoulder position is 3” posterior to rear axle.
- The rear axle is in line with the greater trochanter.
- The push rim is 2” below the elbow (arms at sides).
- The elbows are flexed 100-120° with hands on rims.
**COG relative to rear axle: Impact on w/c performance (cont.)**

<table>
<thead>
<tr>
<th>Forward Axle relative to COG</th>
<th>Posterior Axle relative to COG</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Smaller turning radius – shorter wheel base</td>
<td>• Larger turning radius</td>
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<tr>
<td>• Less stable (tippier)</td>
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</tr>
<tr>
<td><strong>ADV:</strong></td>
<td></td>
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<tr>
<td>• easier wheelie</td>
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<tr>
<td>• easier ↑↓ curbs</td>
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<tr>
<td>• more responsive</td>
<td></td>
</tr>
<tr>
<td><strong>DISADV:</strong></td>
<td></td>
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<tr>
<td>• tippier on inclines</td>
<td></td>
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<tr>
<td>• unstable for users with ↓ trunk control</td>
<td></td>
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<tr>
<td>• ↑ Propulsion efficiency</td>
<td></td>
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<tr>
<td>• force applied over greater span</td>
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<tr>
<td>• ↓ downward turning tendency</td>
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<tr>
<td>• ↓ RR</td>
<td></td>
</tr>
<tr>
<td>• More stable (Less tippity)</td>
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<tr>
<td><strong>ADV:</strong></td>
<td></td>
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<tr>
<td>• less tippier on inclines</td>
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<tr>
<td>• higher balance point for wheelie</td>
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<tr>
<td>• more stable on inclines</td>
<td></td>
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<tr>
<td><strong>DISADV:</strong></td>
<td></td>
</tr>
<tr>
<td>• more difficult to initiate wheelie</td>
<td></td>
</tr>
<tr>
<td>• Less efficient propulsion</td>
<td></td>
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<tr>
<td>• shorter push phase</td>
<td></td>
</tr>
<tr>
<td>• higher stroke frequency</td>
<td></td>
</tr>
<tr>
<td>• ↑ RR</td>
<td></td>
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</table>

**Manual Wheelchair Selection and Fitting:**

(1) **Addressing Impairments**

(2) **Addressing Function**

(3) **Environmental Considerations**

(4) **Considerations for prevention of UE injury**
REFERENCES: Biomechanics of Wheelchair Propulsion


