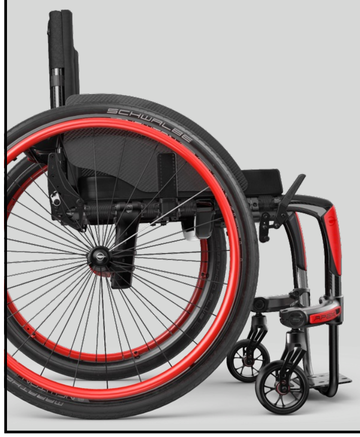

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MOTION COMPOSITES

ANATOMY OF A MANUAL WHEELCHAIR

CLINICAL IMPLICATIONS

PRESENTED BY: ERIN MANIACI, PT, DPT, ATP

ALPINE | OCTOBER 4, 2024

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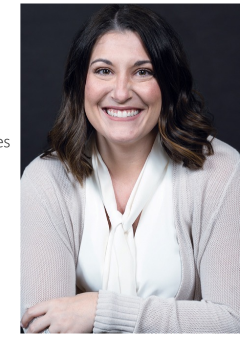
FACULTY DISCLOSURE

ERIN MANIACI, PT, DPT, ATP

- Physical Therapist
  - Inpatient SCI rehab, Amputee inpatient rehab, wheelchair prescription writing, gait training, outpatient neuro
- Current Clinical Education Specialist, Motion Composites
- Based in Phoenix, Arizona
- Grew up in MO → MU Grad → GO CHIEFS & TIGERS

e.maniaci@motioncomposites.com



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GREETINGS FROM MOTION COMPOSITES

INDUSTRY AWARDS

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MOTION COMPOSITES

MISSION, VISION & VALUES

"LEAD THE EVOLUTION OF MOBILITY FOR BETTER LIVING"

"BECOME EVERYONE'S FAVORITE MOBILITY COMPANY BY OFFERING INNOVATIVE PRODUCTS AND THE MOST RESPONSIVE SERVICE"

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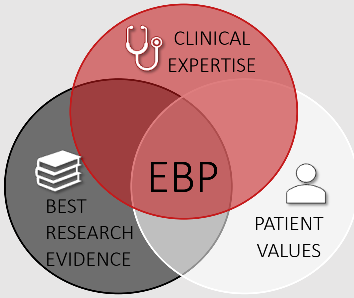
EVIDENCE BASED PRACTICE

OUR FOUNDATION



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Integrating individual clinical expertise with the best available external clinical evidence from systematic research
-David Sackett, 1996

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LEARNING OBJECTIVES

BY THE END OF THIS PRESENTATION PARTICIPANTS WILL BE ABLE TO:

1. Analyze and categorize two factors regarding frame structure that impact manual wheelchair performance.
2. Recognize and classify the three most common materials used in fabricating wheelchair frames.
3. Apply knowledge by recalling two basic parameters of the International Organization of Standardization (ISO) testing for manual wheelchairs.

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WHAT IS IMPORTANT FROM A CLINICAL STANDPOINT?

ACHIEVING GOALS

- Functionality
  - Propulsion
  - Posture
  - Skills acquisition
- Joint protection
- Skin protection
- Comfort (Ride Characteristics)

FEATURES/BENEFITS

- Size/configuration
- Features and benefits
  - Wheel/caster sizes and options
  - Handrim selection
  - Other?
- Lightest wheelchair Possible
  - PVA Clinical Practice Guidelines

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WHAT IS IMPORTANT TO THE CLIENT?

- Aesthetics
- Comfort
- Function
- Performance
- Durability
- Accessories/Components
- Weight

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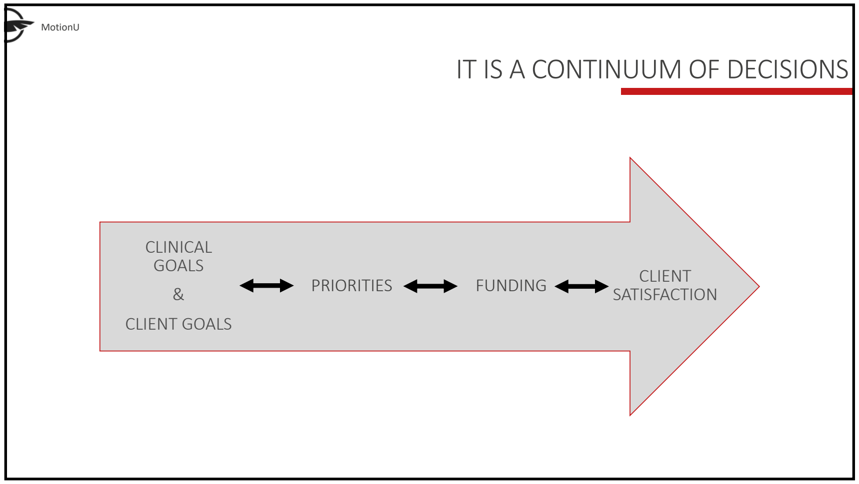
MotionU
IT IS A CONTINUUM OF DECISIONS
CLINICAL GOALS
&
CLIENT GOALS
PRIORITIES
FUNDING
CLIENT SATISFACTION

9


HOW DOES *FORM* IMPACT *FUNCTION*
THE IMPORTANCE OF FRAME GEOMETRY

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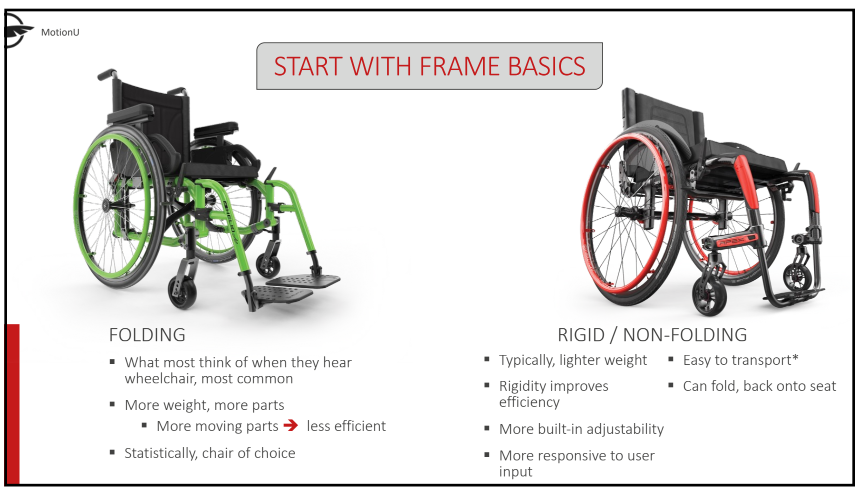
MotionU
START WITH FRAME BASICS
FOLDING
What most think of when they hear wheelchair, most common
More weight, more parts
More moving parts ➔ less efficient
Statistically, chair of choice
RIGID / NON-FOLDING
Typically, lighter weight
Rigidity improves efficiency
More built-in adjustability
More responsive to user input
Easy to transport*
Can fold, back onto seat

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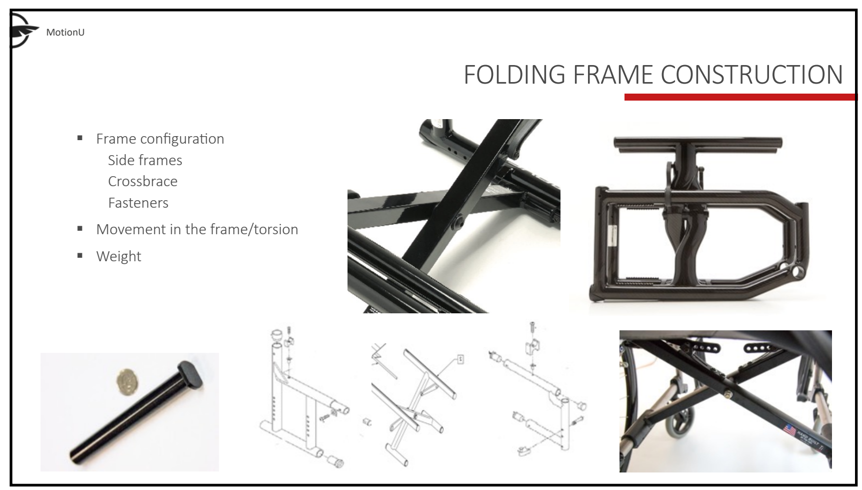
MotionU
FOLDING FRAME CONSTRUCTION
Frame configuration
Side frames
Crossbrace
Fasteners
Movement in the frame/torsion
Weight

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BOX FRAME RIGID CONSTRUCTION

- Most rigid shape/stiffer
- Responsive to user input
- May not disperse “road noise” well
- Easy to construct
- “Old” style
- Difficult to transport
- Example: Quickie GP

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DUAL TUBE RIGID CONSTRUCTION

- Rigid and flexible
- Responsive to user input
- May reduce vibration better than box style
- More complicated to construct
- Stylized frame shapes
- Ease of transport
- Example: AeroT, TRA

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CANTELEVER CONSTRUCTION

- Open frame
- Focus on flexibility
- Vibration damping
- Simpler to construct
- Minimalistic style
- Easy transport
- Compromised lateral stability
- Example: Apex, ZRA, Aero Z, Q7, Nitrum

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FIXED VS. ADJUSTABLE FRAMES

FIXED

- Little or no ability to configure
- More common in rigid style frames

ADJUSTABLE

- Feature can be configured and adjusted throughout lifetime of chair

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FIXED VS. ADJUSTABLE FRAMES

FIXED
- Little or no ability to configure
- More common in rigid style frames

ADJUSTABLE
- Feature can be configured and adjusted throughout lifetime of chair

What will the client look like in 2 months, 3 years, 5 years?
- Adjustability allows to configure for skill acquisition and safety/stability
- Adjust for progress or a regression
- SCI with skill acquisition
- MS that is progressive
- Aging

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CLINICAL CONSIDERATIONS

FIXED
- Consider if all options are fixed or just some
- If COG is fixed, any adjustment made could impact this and then there will be limited ability to adjust over time
- Can be lighter weight
- Client may prefer if they have been involved in several chair prescriptions and know exactly what they want

ADJUSTABLE
- Different manufacturers have varying levels of adjustability
  - 0.5- or 0.25-inch increments
  - infinitely adjustable
- Can be configured over time with skill acquisition or disease progression
- Can be slightly more weight due to hardware
- May be best for a client's first/second/third wheelchair when skill acquisition and return to activity is high

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PARAMETERS OF REAR WHEEL CONFIGURATION

ASSUMING APPROPRIATE FRAME DIMENSIONS

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IMPORTANCE OF REAR WHEEL POSITION

THE EVIDENCE AND INDUSTRY GUIDELINES ARE VERY CLEAR

Research shows that vertical and horizontal wheel position are one of the most important adjustments to minimize impact on the UE during propulsion

-Efficiency

-UE health, preservation

- Rehabilitation Engineering & Assistive Technology Society of North America (RESNA) Position on the Application of Ultralight Manual Wheelchairs, 2022
- Preservation of upper limb function following spinal cord injury: A clinical practice guideline for health-care professionals, (Paralyzed Veterans of America Consortium for Spinal Cord Medicine. 2005)
- Aspects of Manual Wheelchair Configuration Affecting Mobility: A Review. (Medola, FO. Et. Al. 2014)
- Wheelchair axle position effect on start-up propulsion performance of persons with tetraplegia (Freixes et. Al, 2010)

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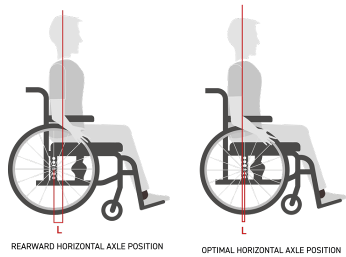
HORIZONTAL AXLE POSITION

- Move the rear axle as far forward as possible without compromising stability of the user
  - At or in front of the shoulder
  - Consider use of anti tips
  - Train clients in wheelies & fall recovery
- Axle position is USER Specific



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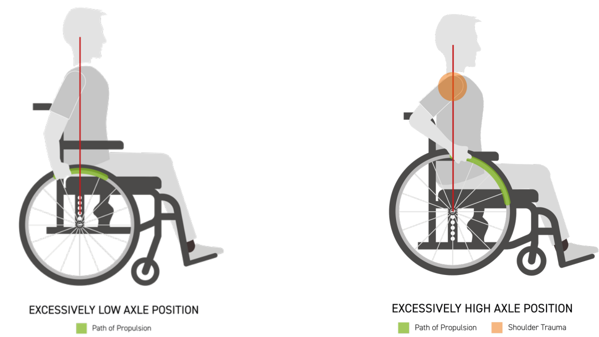
VERTICAL POSITION CHANGES



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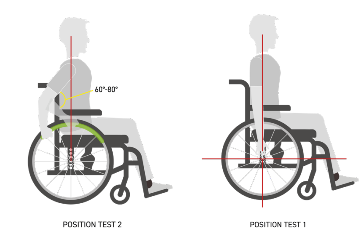
VERTICAL AXLE POSITION

- Angle between the arm and forearm between 100-120 degrees (60-80 degrees of elbow flexion) with hand on top of pushrim
- Middle finger touches the center of the axle with arms hanging
- Can be difficult to optimize with some clients
- Look for:
  - Limited shoulder elevation
  - Reduced extension
  - Decreased external rotation



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OTIMAL REAR WHEEL POSITION

- Results in
  - More efficient propulsion
  - The chair appears to roll easier and “feels lighter”
  - Easier skill acquisition

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MATERIAL CONSIDERATIONS

WHAT SHOULD WE BE CONCERNED WITH?

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FATIGUE

Fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses.

For wheelchairs, we want materials that do not fatigue quickly = durable!

Flexible frames maintain flexibility

Rigid frames maintain rigidity

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DAMPING

- Refers to the materials ability to decrease the amount of vibration transmitted to the user; it is a property of the material and the structure itself.
- A 2021 Systematic Review of the literature found "...vibration induced by MWC propulsion could be affected by many parameters relative to the MWC system (e.g., MWC design, material, suspensions, and cushion)..."
  - All play a role
  - Must fit individual client

Lariviere O, Chadefaux D, Sauret C, Thoreux P. Vibration Transmission during Manual Wheelchair Propulsion: A Systematic Review. *Vibration*. 2021; 4(2):444-481. https://doi.org/10.3390/vibration4020029
https://www.walmart.com/ip/MUMTOP-Wind-Chimes-Bamboo-Product-Wooden-Music-Crisp-Sound
https://www.lowes.com/pd/Exhart-Large-Hand-Tuned-Metal-Wind-Chime-w-Natural-Wood-Top-Silver/1000905678-Garden-Patio-Decor/529638290

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STRENGTH TO WEIGHT RATIO

Strength to weight ratio = strength ÷ weight

- More strength than mass
- Higher strength to weight ratio means
  - Less material needed
  - More durable

Also termed SPECIFIC STRENGTH

20x body weight

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STRENGTH TO WEIGHT RATIO: MOST COMMON WHEELCHAIR MATERIALS

- Steel
  - Low carbon steel
  - Stainless steel
  - Chrome-Molly
- Aluminum Alloy
- Titanium
- Carbon

Material	Strength to Weight Ratio[1] kN-M/Kg (force per meter divided by weight)
Al 6061 T6	115
Al 7075	204
Stainless Steel	63.1
Chrome Molly	71-85
Titanium Alloy	260
Carbon Fiber	2457

1. *"ASM Material Data Sheet"*. asm.matweb.com.

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ALUMINUM

PROS

- Cost
- Easy to work with
- Good corrosion resistance
- Easy to access

CONS

- Fatigue life
- Weight

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TITANIUM

PROS

- Good strength to weight ratio
- Fatigue life
- Corrosion resistance
- Impact resistance

CONS

- Difficult to manufacture
- Cost for raw material

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WHAT DO WE KNOW ABOUT ALUM/TI MANUFACTURING?

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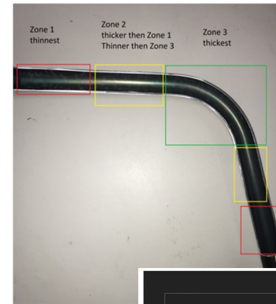
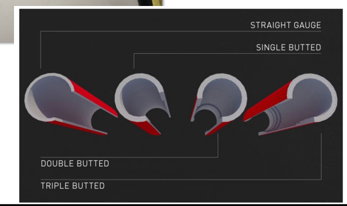
BUTTING

- Thicker in areas where additional strength is required
- Reduces weight where it is not needed





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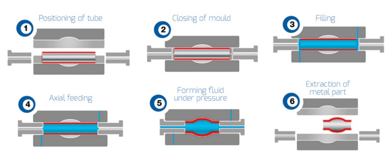
HYDROFORMING

- Shaping metals using a mold and fluid.
- Tubing is placed into a mold that is a specific shape.
- Inject fluid at high pressures causing the aluminium to press into the mold and take the intended shape.
- Commonly used to optimize tube shapes for additional stiffness without requiring extra material to be used as reinforcement.



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CARBON FIBER (COMPOSITES)

PROS

- High strength to weight ratio
- Vibration damping
- Weight
- Not impacted by heat/cold
- Finite manufacturing control of the material
  - Can be molded into elaborate shapes

CONS

- Manufacturing costs
  - Molds
  - Price of raw material
- Impact resistance*

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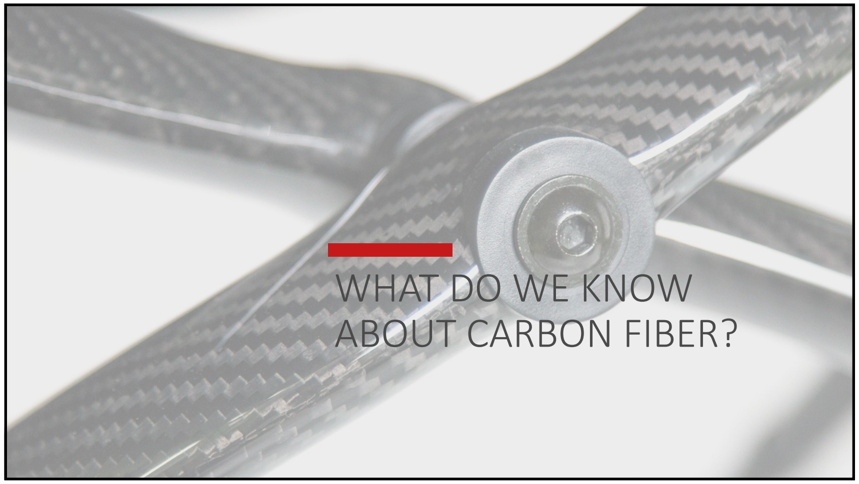

WHAT DO WE KNOW ABOUT CARBON FIBER?

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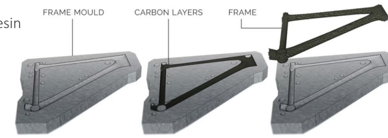
WHAT IMPACTS STRENGTH & QUALITY?

- Manufacturing technique
  - Bladder molds
  - Layering
  - Braiding
  - Wrapping
- The number and direction of layers
- The type and amount of resin used



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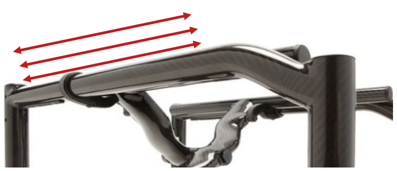
LAYERS & DIRECTION



PARALLEL LAYERS

- STRONG IN A PARTICULAR DIRECTION
- ON SEAT RAIL AND SIDE FRAME, PARALELL LAYERS FOR STABILITY IN ONE DIRECTION

VARYING ANGLED LAYERS

- INCREASED STRENGTH IN MULITPLE DIRECTIONS
- WHERE CASTER HOUSING INTEGRATES WITH THE FRAME

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MATERIAL PROPERTIES COMPARISON CHART: Ultralightweight Manual Wheelchairs

ALUMINUM ALLOYS	CARBON FIBER	TITANIUM
Lowest strength to weight ratio	Highest strength to weight ratio	Good strength to weight ratio
Isotropic material (properties are not direction dependent) • Material properties remain the same in all directions • To increase durability, may sacrifice on weight due to increased thickness of material in areas of wheelchair that withstand more forces	Anisotropic material (properties are direction dependent) • Fibers can be organized in different directions • Fibers organized depending on forces present in that area • increases durability and keeps product as light as possible	Isotropic material (properties are not direction dependent) • Material properties remain the same in all directions • To increase durability, may sacrifice on weight due to increased thickness of material in areas of wheelchair that withstand more forces
Poor fatigue life	Capable of infinite fatigue life Durable and long lasting	Good fatigue life Durable and long lasting
Easier to access & manufacture • Welding, hydroforming, tube manipulation	Specialized manufacturing techniques/factory required	Specialized manufacturing techniques/welding required
Corrosion resistant	Corrosion resistant	Corrosion resistant
Not impact resistant. If damaged, will not perform the same as it did initially	Not impact resistant. If damaged, looks catastrophic and requires professional repairs	Impact resistant. If damaged, will not perform the same as it did initially
Lower raw material cost/more cost-effective compared to carbon fiber and titanium	More costly than aluminum	More costly than aluminum
Typically funded in more markets with clinical justification	Not typically funded unless specific clinical justification provided	Not typically funded unless specific clinical justification provided
Common alloys in our industry • Alloys indicate different mixtures of elements in the material • Different alloys alter the characteristics of the metal, durability, flexibility, etc.	Can build in flexibility and rigidity	More rigid than carbon fiber
Inherently does not possess vibration damping properties	Vibration damping – Dissipates energy quickly, smoother ride, e.g. If one side of the frame is vibrating, it won't reach the other side Molded into elaborate/functional shapes Heat/cold resistance (low thermal expansion)	Inherently does not possess vibration damping properties

*PDF available on MC website

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MATERIAL PROPERTIES LEAD TO JUSTIFICATION

- Connecting the material property with clinical justification
- Symptoms, diagnosis, prognosis

Example:

- Carbon fiber provides vibration damping, which allows XXXX to have a smoother ride in the manual wheelchair. XXXX has a significant history of fatigue and extensor tone in her LEs. After trial with a CF ULWC, she reports less fatigue at the end of the day as well as her LEs not falling off of her footplate due to her tone. With a CF wheelchair, XXXX will spend less time and energy repositioning throughout the day and will be safer at high speeds as her feet will remain on the footplate.

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LIFETIME WARRANTY

You can measure a manufacturer's confidence in its products by the length of its warranty.

Motion Composites built its reputation on the unique attributes of carbon fiber in the wheelchair industry. Now we guarantee it.

Applies to manufacturing defects of the carbon fiber frame and cross brace.

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WHAT TO REMEMBER

- Not all materials are created equal
- Manufacturing technique can play an important role
- Structure impacts function
- Improve efficiency
- UE preservation/Client health
- Configuration still matters!

➡ It will unlock the full potential!

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WHAT HELPS US TO CHOOSE?

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THERE ARE STANDARDS

- **ISO**: International Organization for Standardization
- **ANSI**: American National Standards Institute
- **RESNA**: Rehabilitation Engineering and Assistive Technology Suppliers of North America
- AU/NZ Standards
- EU Standards

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HOW CAN I LEARN MORE ABOUT PRODUCT PERFORMANCE?

WHAT ARE PERFORMANCE STANDARDS?

Test specifications describing procedures to measure product performance using quantifiable, reliable performance metrics

Where can I find testing results for my product?

- Results are generally not publicly available. Manufacturers should be contacted for this information.

Who performs these standardized tests?

- Tests are performed by manufacturers and independent testing facilities

How do I benefit from product performance standards, if I am a...

PRODUCT USER
Users can use standardized performance measures to ask relevant questions about which product best meets their individual needs

MANUFACTURER
Manufacturers can use standardized performance methods for internal verification testing and to create quantifiable data to back up marketing claims, setting themselves apart from competitors

HEALTHCARE PROVIDER
Healthcare providers can use standardized performance measures as a way to compare products on the market, make informed decisions and provide their clients with a product that most closely meets their needs

POLICY MAKER
Policy makers can adopt standardized testing with pass/fail criteria for device regulation and reimbursement

Where can I get involved and learn more about the existing standards?

- RESNA Standards Activities
  - https://www.resna.org/AT-Standards
- International Organization for Standardization Activities
  - https://www.iso.org/committee/53792/x/catalogue/
- International Society of Wheelchair Professionals
  - https://wheelchairnetwork.org/kbtopic/testing-methods/
- University of Pittsburgh Wheelchair & Cushion Standards Group
  - https://wheelchairstandards.pitt.edu
  - https://www.linkedin.com/company/65529247/

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The contents of this fact sheet were developed under a grant from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR grant number 90REGE0001-01-00). The contents are not endorsed by the Federal Government.

https://www.wheelchairstandards.pitt.edu/fact-sheets

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WHY THE STANDARDS EXIST

- Reduces inconsistencies
- Provide uniform methods for analyzing wheelchairs and prescribing the chair by therapists
- ISO sets minimum performance criteria
- The ISO standards also include maximum values for certain characteristics, including mass, stability, turning space, and dimensions of a wheelchair, such as overall length, width, and height.

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B. GEBROSKY ET AL., 2020

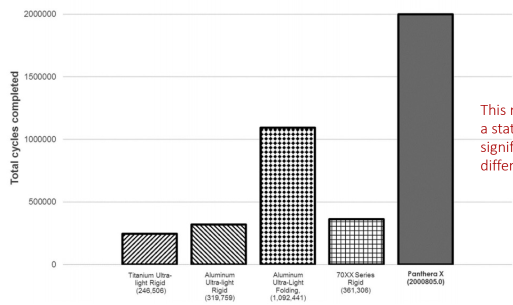

Figure 7. Mean equivalent cycles completed for this study and previous studies.

This represents a statistically significant difference

Benjamin Gebrosky, Garrett Grindle, Rosemarie Cooper & Rory Cooper (2020) Comparison of carbon fibre and aluminium materials in the construction of ultralight wheelchairs, Disability and Rehabilitation: Assistive Technology, 15:4, 432-441, DOI: 10.1080/17483107.2019.1587018

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Comparison of carbon fibre and aluminium materials in the construction of ultralight wheelchairs

IMPLICATIONS FOR REHABILITATION

- Carbon fibre wheelchair construction is a viable alternative to aluminium, titanium, or steel construction,
- Decreasing costs will continue to improve the benefits of carbon fibre over these models
- Carbon fibre wheelchair found to be more durable than aluminium models but are also much more expensive.
- The additional cost may be justified for some users that need the increased durability.
- Increased durability will reduce the number of repairs and warranty claims, potentially reducing the burden on a wheelchair user, and also improving their ability to travel and participate in their community
- The low weight of carbon fibre wheelchairs may increase the mobility of some users by allowing them to transfer more easily into and out of vehicles and manoeuvre throughout the environment

GREAT JUSTIFICATIONS!

B. GEBROSKY ET AL., 2020

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B. GEBROSKY ET AL., 2020

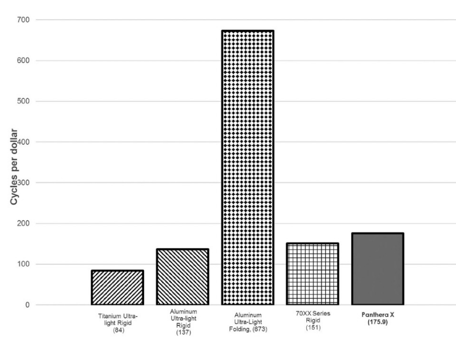

Figure 8. Cost benefit analysis of the current and previously reported wheelchair studies.

Remember to look at the full picture…

Benjamin Gebrosky, Garrett Grindle, Rosemarie Cooper & Rory Cooper (2020) Comparison of carbon fibre and aluminium materials in the construction of ultralight wheelchairs, Disability and Rehabilitation: Assistive Technology, 15:4, 432-441, DOI: 10.1080/17483107.2019.1587018

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COST ≠ PRICE

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IS THE WHEELCHAIR COST EFFECTIVE?

MANUFACTURING COST EFFECTIVENESS

- How easy is the material to work with?
- Does it require specialty manufacturing techniques?
- What is the cost of material?
- Are there functional benefits to material utilization?

CLINICAL COST EFFECTIVENESS

- How much does it cost to operate over time?
- Durability
- Ability to customize for specific clients
- Warranty

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WHICH IS BEST?

It depends on priorities……go back to your goals!

Possible Considerations

- Stability
- Stiffness
- Vibration Damping
- Weight
- CONFIGURABILITY

Trial and compare as needed or are able in your market

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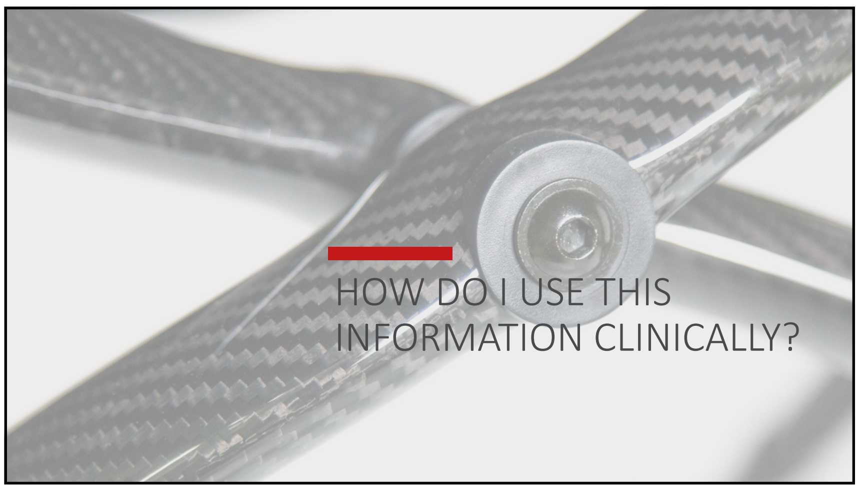

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CONFIGURATION:

THE ULTIMATE CONSIDERATION

- Set up of the wheelchair
  - Wheel position
  - Frame fit (width, depth)
  - Footrest position and support
  - Backrest selection and position
- Accessory choices
  - Rear wheels and tires
  - Caster size and type
  - Seating surfaces

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GIVE YOUR CLIENT OPPORTUNITY FOR SUCCESS

- Prioritize clinical goals
  - Anticipate client functional level
  - Consider client's wish list
- Assess based on most appropriate, not "Good Enough"
- Examine cost vs. price realistically, not in relation to funding
- Don't make assumptions about client's ability and expectations
- Risks v. Benefits

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UNDERSTAND THE PRODUCTS

- Expect a level of knowledge from suppliers
- Take a critical look at new products – ask questions!
- Learn about the options – don't just rely on your partners
  - Understand the features and benefits
  - Understand why options exist
- Don't be afraid to try new things

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KEYS TO OPTIMIZING PERFORMANCE

- CONFIGURATION
- MATERIAL TYPE
- FRAME STRUCTURE

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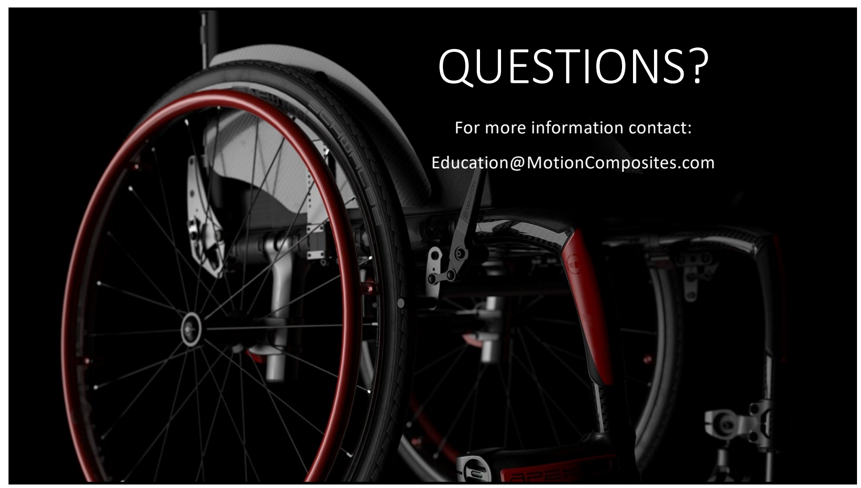

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CARBON FIBER JUSTIFICATION

CARBON FIBER (CF) properties are shown with their correlating clinical impairments and should be used to assist with justification. The clinician must relate the CF property to a clinical impairment or environmental need. The justification should reiterate that the CF is required for independent completion of a functional activity, ease of maneuverability, and in turn, will provide the best outcomes and QOL for the client.

CLIENT IMPAIRMENTS/ENVIRONMENTAL NEEDS	CARBON FIBER PROPERTY
▪ Upper extremity weakness, paralysis or paresis ▪ High risk of upper extremity overuse injury ▪ History of repetitive strain injuries ▪ Limited ROM in upper extremities ▪ Contractures of upper extremity joints ▪ Sitting instability due to trunk weakness or postural deformities ▪ Full-time user, requires wheelchair >6 hours/day ▪ Fatigue ▪ Limited energy expenditure, decreased endurance ▪ Lifting in & out of the vehicle (also applies to the caregiver) ▪ Need for maneuverability	High Strength to Weight Ratio Exceptionally Lightweight
▪ High risk of upper extremity overuse injury ▪ History of repetitive strain injuries ▪ Neuropathic pain ▪ Musculoskeletal pain ▪ Limited or absent sensation, at risk for pressure injury ▪ Sitting instability due to trunk weakness or postural deformities ▪ Limited sitting tolerance when rolling over thresholds or uneven terrain ▪ Fatigue ▪ Tone ▪ Spasticity	Vibration Damping
▪ Vigorous user that requires a durable, yet responsive frame ▪ Live in a remote location ▪ Unable to maintain minor adjustments on their own ▪ Limited access to their supplier for maintenance ▪ Potential for wheelchair abandonment	Infinite Fatigue Exceptional Durability
▪ Live in extreme temperatures or wet environments	Corrosion Resistant Low Thermal Expansion

References: https://www.resna.org/sites/default/files/legacy/resources/position-papers/UltraLightweightManualWheelchairs.pdf

MATERIAL PROPERTIES COMPARISON CHART: Ultralightweight Manual Wheelchairs

ALUMINUM ALLOYS	CARBON FIBER	TITANIUM
Lowest strength to weight ratio	Highest strength to weight ratio	Good strength to weight ratio
Isotropic material (properties are not direction dependent) • Material properties remain the same in all directions • To increase durability, may sacrifice on weight due to increased thickness of material in areas of wheelchair that withstand more forces	Anisotropic material (properties are direction dependent) • Fibers can be organized in different directions • Fibers organized depending on forces present in that area • increases durability and keeps product as light as possible	Isotropic material (properties are not direction dependent) • Material properties remain the same in all directions • To increase durability, may sacrifice on weight due to increased thickness of material in areas of wheelchair that withstand more forces
Poor fatigue life	Capable of infinite fatigue life Durable and long lasting	Good fatigue life Durable and long lasting
Easier to access & manufacture • Welding, hydroforming, tube manipulation	Specialized manufacturing techniques/factory required	Specialized manufacturing techniques/welding required
Corrosion resistant	Corrosion resistant	Corrosion resistant
Not impact resistant. If damaged, will not perform the same as it did initially	Not impact resistant. If damaged, looks catastrophic and requires professional repairs	Impact resistant. If damaged, will not perform the same as it did initially
Lower raw material cost/more cost-effective compared to carbon fiber and titanium	More costly than aluminum	More costly than aluminum
Typically funded in more markets with clinical justification	Not typically funded unless specific clinical justification provided	Not typically funded unless specific clinical justification provided
Common alloys in our industry • Alloys indicate different mixtures of elements in the material • Different alloys alter the characteristics of the metal, durability, flexibility, etc.	Can build in flexibility and rigidity	More rigid than carbon fiber
Inherently does not possess vibration damping properties	Vibration damping – Dissipates energy quickly, smoother ride, e.g. If one side of the frame is vibrating, it won't reach the other side	Inherently does not possess vibration damping properties
	Molded into elaborate/functional shapes	
	Heat/cold resistance (low thermal expansion)	

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