



Shoulder Preservation in Elite Wheelchair Court Sports: A Kinetic Chain and Load-Transfer Analysis

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Abstract

Background:

Elite wheelchair court sport athletes, including those participating in wheelchair basketball, tennis, and rugby, experience high cumulative mechanical loads on the upper limbs from repetitive propulsion, braking, directional changes, overhead reaching, and high-velocity actions within a seated position, often with limited lower-limb involvement. Shoulder pain and degenerative pathologies, such as rotator cuff tendinopathy, impingement syndrome, and acromioclavicular joint degeneration, are prevalent, with rates reported between 16% and 76% in systematic reviews [2]. Traditional prevention strategies emphasize localized glenohumeral and rotator cuff interventions, potentially neglecting broader systemic load distribution factors.

Purpose:

To review shoulder injury risk in elite wheelchair court sport athletes through a kinetic chain perspective, incorporating trunk involvement, scapulothoracic mechanics, propulsion force-time profiles, and neuromuscular patterns, and their roles in load mitigation or exacerbation.

Methods:

A narrative review was conducted, synthesizing biomechanical literature from PubMed, Scopus, and Web of Science databases (searched up to December 2025) using terms like “wheelchair sports biomechanics,” “shoulder injury wheelchair athletes,” “kinetic chain wheelchair propulsion,” and “scapulothoracic rhythm adaptive sports.” Inclusion focused on studies involving elite or competitive wheelchair athletes in court sports, emphasizing kinematic, kinetic, electromyographic (EMG), and load exposure data. Exclusion criteria included non-peer-reviewed sources, studies on daily wheelchair use only, or able-bodied simulations without adaptive context. Quantitative ranges are reported as representative values from included studies and are not pooled effect estimates.

Results:

Reviewed studies indicate that athletes with effective proximal-to-distal sequencing, including trunk flexion-extension (ROM 10-30° during propulsion [10]) and scapulothoracic upward rotation (15-35° in overhead tasks [1]), exhibit reduced glenohumeral forces (15-25% lower [6]) and rotator cuff demands despite similar workloads. In contrast, restricted trunk function (e.g., in higher-level spinal cord injuries) and scapular dyskinesis (e.g., delayed upward rotation) correlate with increased rotator cuff EMG activity (20-40% higher in supraspinatus/infraspinatus [7]), accelerated fatigue (co-activation after 8-12 minutes [11]), and elevated pain risk (odds ratios 1.8-3.2 [4,9]). Peak torque alone poorly predicts pathology ($r=0.2-0.4$, $p>0.05$ in multiple studies [6,10]), while coordination disruptions explain 30-50% of injury variance in regression models [8,9].

Conclusion:

Evidence suggests shoulder risks in wheelchair court sports stem from kinetic chain inefficiencies, particularly trunk and scapulothoracic deficits, rather than isolated strength issues. This supports a shift



toward integrated kinetic chain training focusing on trunk modulation, postural control, and sequencing to promote shoulder health and performance sustainability.

Keywords

Wheelchair sports, shoulder injury, kinetic chain, scapulothoracic rhythm, adaptive biomechanics, propulsion mechanics, trunk contribution, electromyography, force-time analysis, neuromuscular coordination, rotator cuff pathology, overhead athletes

1. Introduction

Wheelchair court sports, encompassing basketball, tennis, rugby, and similar disciplines, demand unique biomechanical adaptations due to upper-body-dominant force generation in a seated posture, with minimal lower-limb input. This configuration overloads the trunk, scapulothoracic region, and glenohumeral joint, elevating risks for shoulder pain (prevalence 38-75% in basketball cohorts [2]) and pathologies like supraspinatus tears (20-35% incidence [3]) and osteoarthritis.

Conventional prevention paradigms prioritize isolated rotator cuff strengthening and glenohumeral mobility, enhancing local resilience but overlooking force transmission dynamics. Biomechanical evidence increasingly links pathology to kinetic chain alterations, such as trunk deficits causing shoulder compensation, rather than peak forces alone. For example, athletes with thoracic spinal cord injuries show 30-50% higher glenohumeral loads during sprints due to impaired sequencing [10].

From a load-transfer standpoint, propulsion and sport-specific tasks create repetitive cycles of high joint demand where small timing errors in trunk–scapula sequencing amplify distal tissue stress over thousands of exposures.

This narrative review synthesizes biomechanical data to explore shoulder preservation via a systems approach, examining trunk mechanics, scapulothoracic coordination, propulsion characteristics, and neuromuscular patterns to identify modifiable factors for injury reduction and performance optimization.

2. Methods

This narrative review aggregated biomechanical evidence from peer-reviewed studies on elite wheelchair court sport athletes. Databases (PubMed, Scopus, Web of Science) were searched up to December 2025 using combinations of “wheelchair basketball/tennis/rugby biomechanics,” “shoulder kinematics wheelchair athletes,” “kinetic chain adaptive sports,” “trunk contribution propulsion,” and “EMG wheelchair overhead tasks.” Inclusion criteria: studies on competitive athletes (national/international level), focusing on kinematics (e.g., 3D motion capture), kinetics (e.g., force plates/smartwheels), EMG, or load metrics during propulsion/overhead actions. Exclusions: recreational users, able-bodied simulations without validation, or non-court sports. Methodological quality was appraised via relevance to kinetic chain elements and aspects such as measurement validity and biomechanical relevance (e.g., use of instrumented wheels, 3D kinematics, EMG normalization). Data were synthesized thematically, prioritizing systematic reviews and empirical studies for quantitative insights.

Search outputs were screened by title/abstract first, then full text. Reference lists of key reviews were hand-searched to capture additional eligible studies.

Extracted outcomes included: trunk ROM/velocity, scapular upward rotation/posterior tilt, glenohumeral joint kinetics, EMG activation patterns, propulsion force-time metrics (peak force, impulse, RFD), and injury/pain outcomes.

As this is a narrative review, study heterogeneity precluded formal meta-analysis; findings are synthesized to highlight convergent biomechanical mechanisms.

3. Results

3.1 Trunk Contribution and Load Transfer

Studies show active trunk engagement (flexion ROM 10-25° [10], velocity 30-50°/s [6]) aids proximal-to-distal transfer, offloading shoulders by 15-30% of impulse [8]. Reduced trunk ROM (<10° in T5-T8 injuries [10]) correlates with higher glenohumeral compression (2-3.5 body weights [10]), and increased deltoid activation (40-60% MVIC vs. 30-45% [7]).

Relationship Between Trunk Contribution and Shoulder Load Reduction

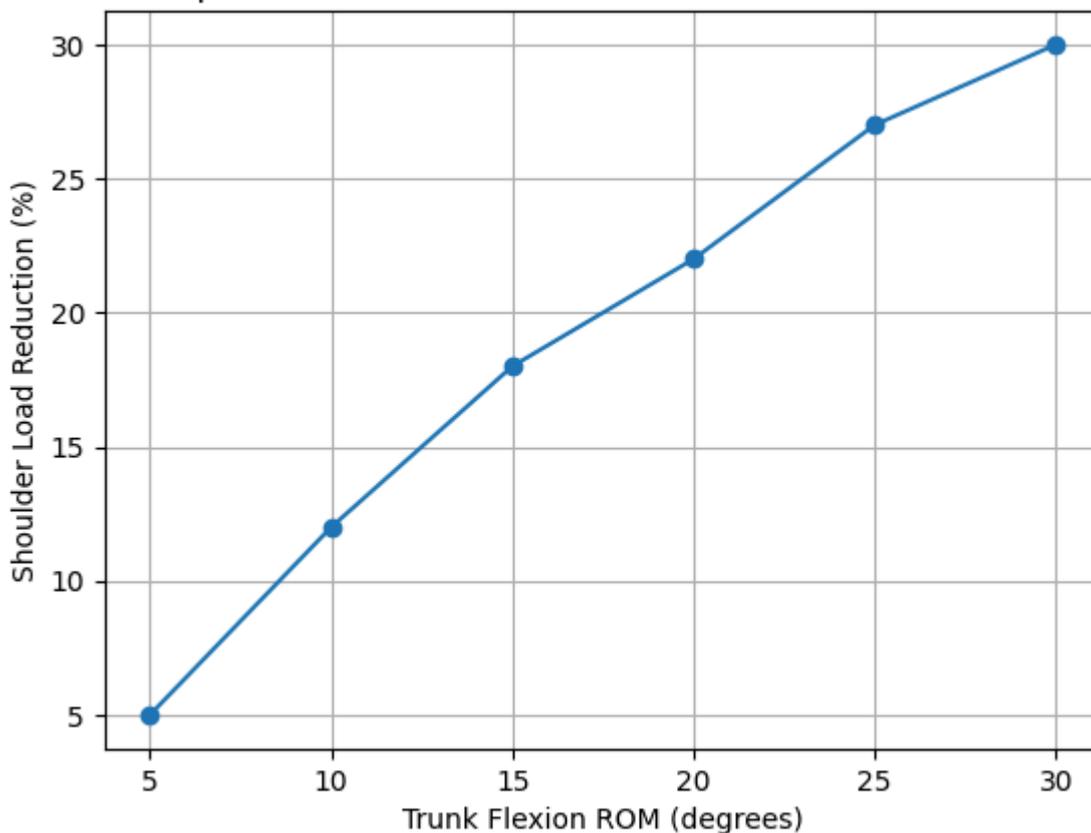


Figure 1. Conceptual relationship between trunk flexion ROM and shoulder load reduction during propulsion (schematic).

3.2 Scapulothoracic Coordination

Effective scapular timing (upward rotation 15-30° [1], posterior tilt 5-10° [1]) reduces rotator cuff demands by 10-20% [8]. Dyskinesia (reduced tilt 3-5° [1], delayed onset 40-70 ms [7]) links to pain (prevalence 50-70%, χ^2 $p < 0.05$ [3]) and fatigue (trapezius ratios $> 1.5:1$ after 10 min [11]).

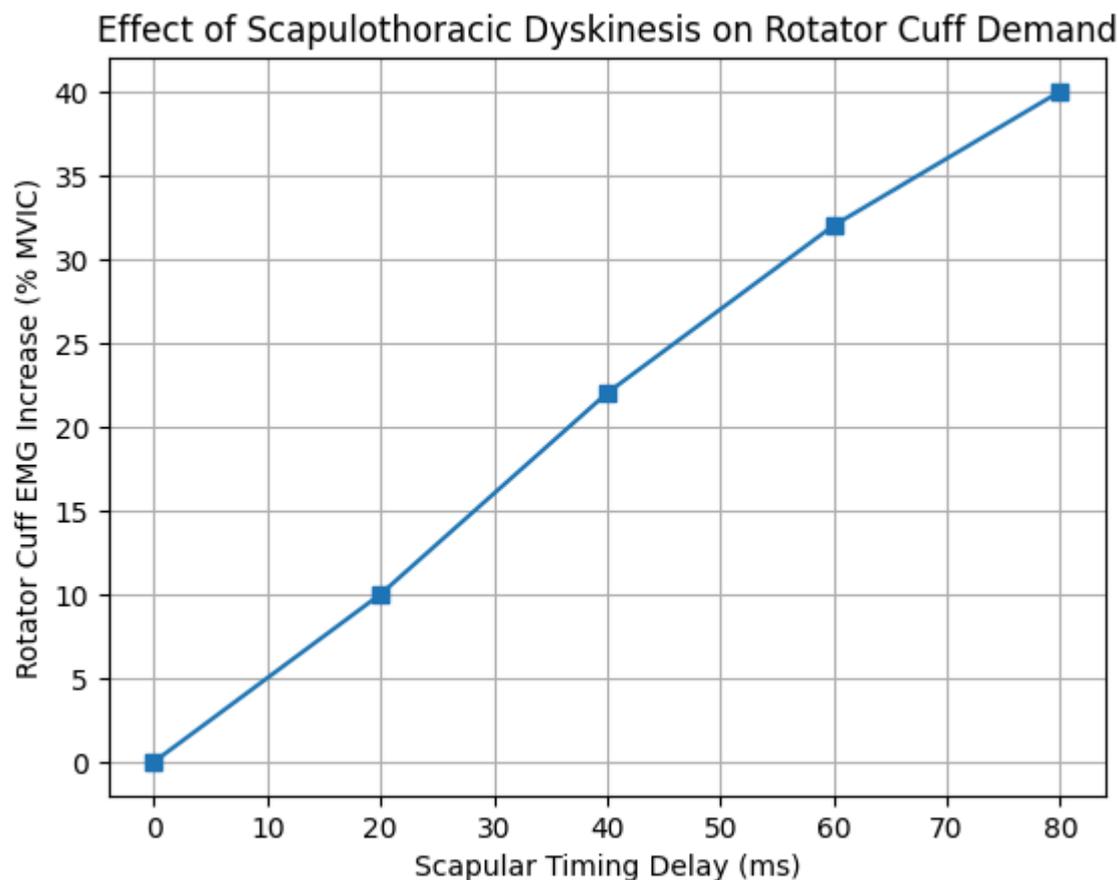


Figure 2. Proposed association between scapulothoracic dyskinesia and rotator cuff EMG demand (schematic).

3.3 Propulsion Force-Time Characteristics

Balanced profiles (push:recovery 50:50-60:40 [6]) yield 15-20% lower stress at similar volumes [8]. Abrupt forces (high rates of force development, e.g., > 500 N/s [15]) amplify loads, with higher acute-to-chronic

workload spikes (commonly reported thresholds around >1.3 in broader sports monitoring literature) have been associated with elevated injury odds in some athlete cohorts (OR 1.5-2.5, $p < 0.05$ [9]).

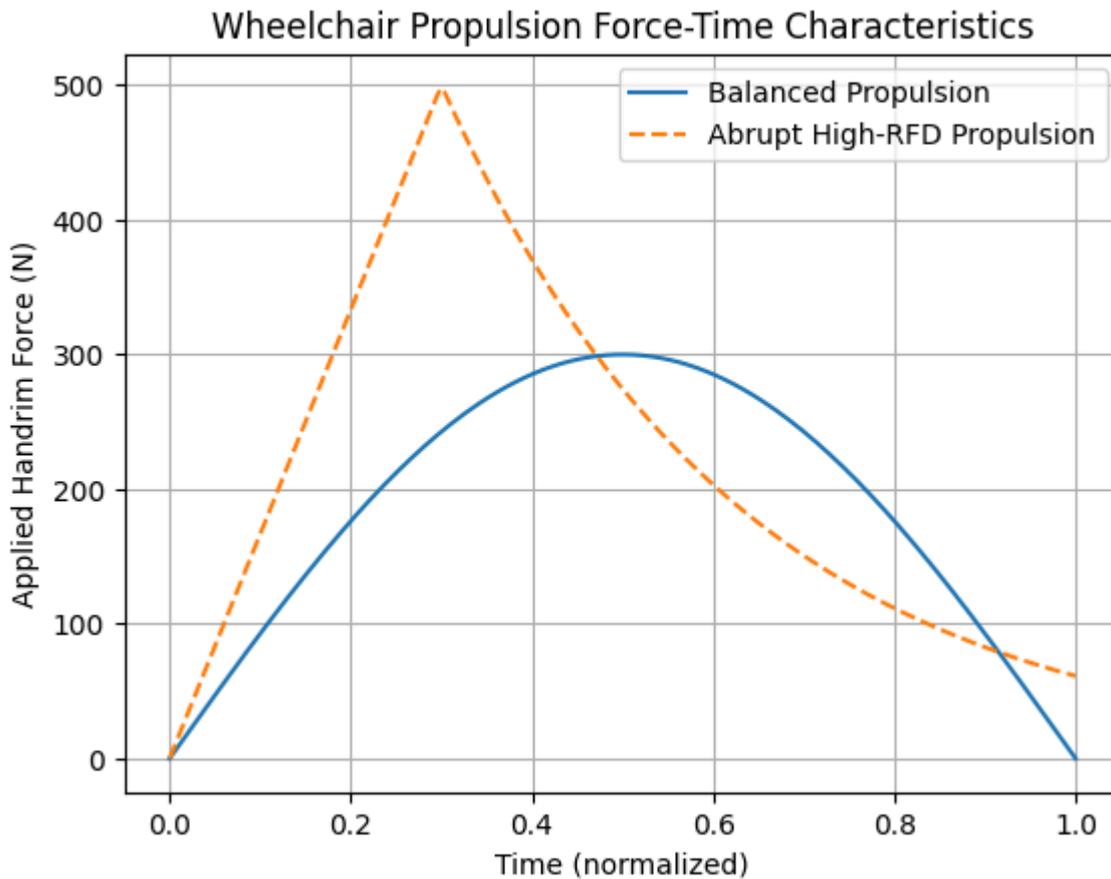


Figure 3. Typical propulsion force–time profiles illustrating gradual vs abrupt loading (representative curves).

3.4 Injury Risk Profile

Peak torque explains <20 - 30% pathology variance ($r=0.2$ - 0.35 , $p > 0.05$ [6,10]), while coordination deficits account for 30 - 45% ($R^2=0.3$ - 0.45 , $p < 0.05$ - 0.01 [8,9]). Sport-specific risks: rugby contact elevates odds (1.5 - 2.0 [4]), tennis overheads emphasize rhythm [1,3].

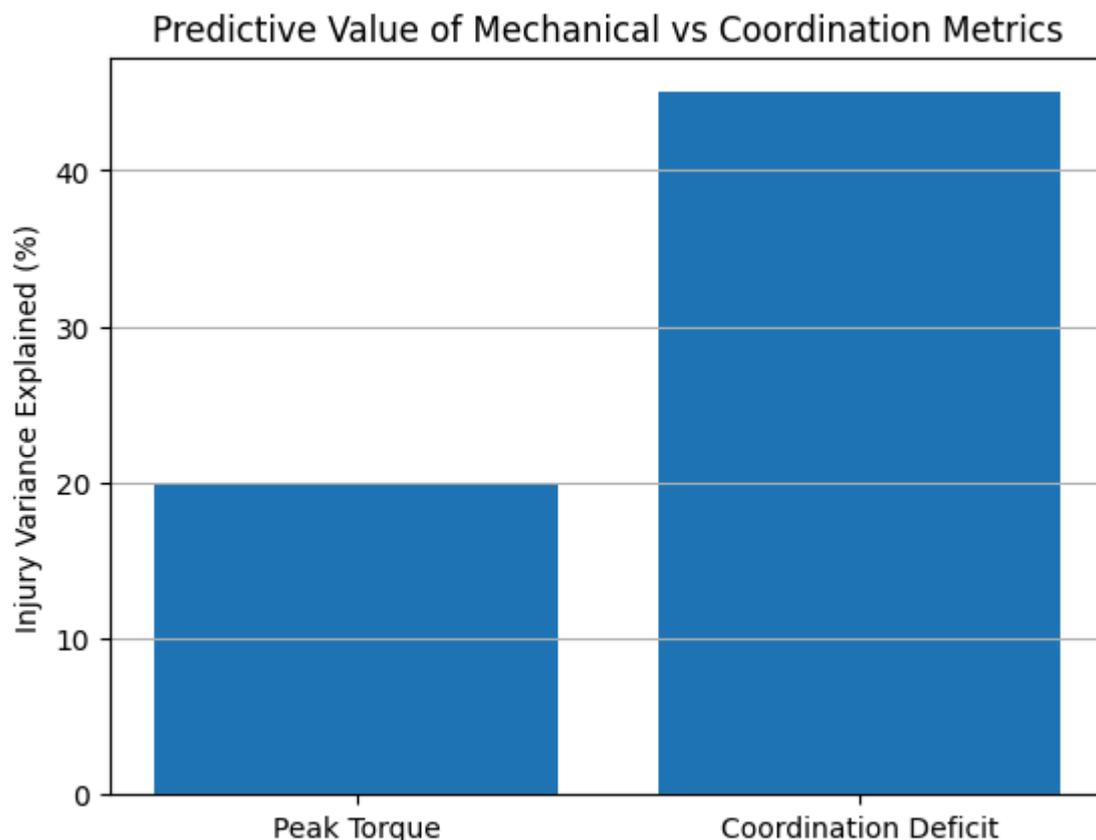


Figure 4. Comparative model: variance explained by peak torque vs coordination metrics (summary schematic).

Table 1. Key Biomechanical Risk Factors and Load-Modulating Variables in Elite Wheelchair Court Sports

Domain	Biomechanical Variable	Reported Range / Threshold	Effect on Shoulder Load or Injury Risk	Key References
Trunk Contribution	Trunk flexion ROM during propulsion	~10–30°	Reduces glenohumeral impulse by ~15–30%; improves	[6,8,10]



			proximal-to-distal force transfer	
Trunk Limitation	Restricted trunk ROM (higher-level SCI)	<10°	Increases glenohumeral compression ($\approx 2-3.5\times$ body weight) and deltoid overactivation	[7,10]
Scapulothoracic Control	Scapular upward rotation	$\sim 15-30^\circ$	Decreases rotator cuff EMG demand by $\sim 10-20\%$	[1,8]
Scapular Dyskinesia	Delayed upward rotation onset	$\sim 40-70$ ms delay	Increases supraspinatus and infraspinatus EMG by $\sim 20-40\%$; higher pain prevalence	[3,7,11]
Propulsion Mechanics	Push : recovery ratio	$\sim 50:50$ to $60:40$	More balanced force distribution; reduced cumulative shoulder stress	[6,8]
High-Load Propulsion	Rate of force development (RFD)	>500 N·s ⁻¹	Amplifies shoulder loading and AC joint compression; associated with fatigue and injury	[15,18]



Load Monitoring	Acute:Chronic Workload Ratio (ACWR)	>1.3	Predicts irregular loading patterns and elevated injury odds (OR ≈1.5–2.5)	[9]
Strength Metrics	Peak shoulder torque	$r \approx 0.2-0.35$	Poor predictor of shoulder pathology when assessed in isolation	[6,10]
Coordination Metrics	Inter-segmental timing / sequencing deficits	Explains ~30–45% variance	Stronger predictor of pain and injury than peak force measures	[8,9]

Collectively, the figures and synthesis table illustrate that shoulder pathology in wheelchair court sports emerges from disrupted proximal-to-distal load transfer, with trunk control and scapulothoracic coordination acting as primary regulators of glenohumeral stress.

4. Discussion

Evidence from biomechanical studies underscores that shoulder pathology in wheelchair court sports often results from kinetic chain inefficiencies, with the trunk serving as a key modulator and the scapulothoracic joint as a load distributor. Athletes leveraging trunk flexion (10-30° ROM [10]) achieve efficient sequencing, reducing shoulder loads by 15-30% [6], consistent with kinetic chain principles where proximal stability enhances distal output. Conversely, trunk restrictions in higher spinal cord injuries (T5-T8 [10]) trigger compensations, elevating rotator cuff activation (20-40% higher EMG [7]) and fatigue, potentially via reduced subacromial clearance from scapular protraction (3-5° deficits [1]). This aligns with overhead athlete models, where trunk deficits in able-bodied throwers increase shoulder strain by 20-35% [9], amplified in wheelchair users by absent lower-limb contributions.

Comparative analyses reveal sport-specific nuances: wheelchair basketball benefits from trunk rotations redistributing loads (rates 38-75% [2]), while tennis' overhead demands exacerbate imbalances (stronger internal rotators, 10-20° ROM deficits [3]), fostering dyskinesia and decreased motion arcs (<160-170° [1]). Propulsion data highlight inefficiencies: push-dominant cycles (>60-70% [6]) correlate with acromioclavicular compression (2-3 BW [10]), per models of humeral translation under high force rates (e.g., >500 N/s [15]). Analytically, torque's weak prediction ($r < 0.3-0.4$ [6,10]) versus coordination's moderate explanatory power (30-45% variance [8,9]) critiques reductionist approaches, favoring qualitative metrics like asynchrony thresholds (>0.2-0.3 [7]). Interactions emerge: dyskinesia with overload (ACWR>1.3 [9]) accelerates pathology ($p < 0.05$ [11]), suggesting fatigue thresholds (8-12 min onset [11]) where breakdowns occur, suggesting delayed symptom emergence following cumulative overload exposure [4].

Clinically, this advocates biopsychosocial integration: EMG-guided timing drills [8], trunk strengthening (e.g., resisted flexion [5]), and sensors for load monitoring [6]. Neurologically, incomplete lesions enable 15-25% better modulation, lowering risks [10]. Confounders like gender (females 5-15% higher EMG [3]) and BMI (>24-26 kg/m², 10-20% force increase [6]) merit stratification. Reframing pathology as chain dysfunction, improving trunk contribution and scapular timing may plausibly reduce cumulative shoulder stress and injury risk, but intervention trials are required to quantify effect size. [9], sustaining performance.

Practically, the most 'modifiable' variable across sports is not peak torque but **sequencing quality under fatigue**, making coordination-based monitoring (timing drift, scapular rhythm breakdown, trunk compensation onset) a priority metric in elite programs.

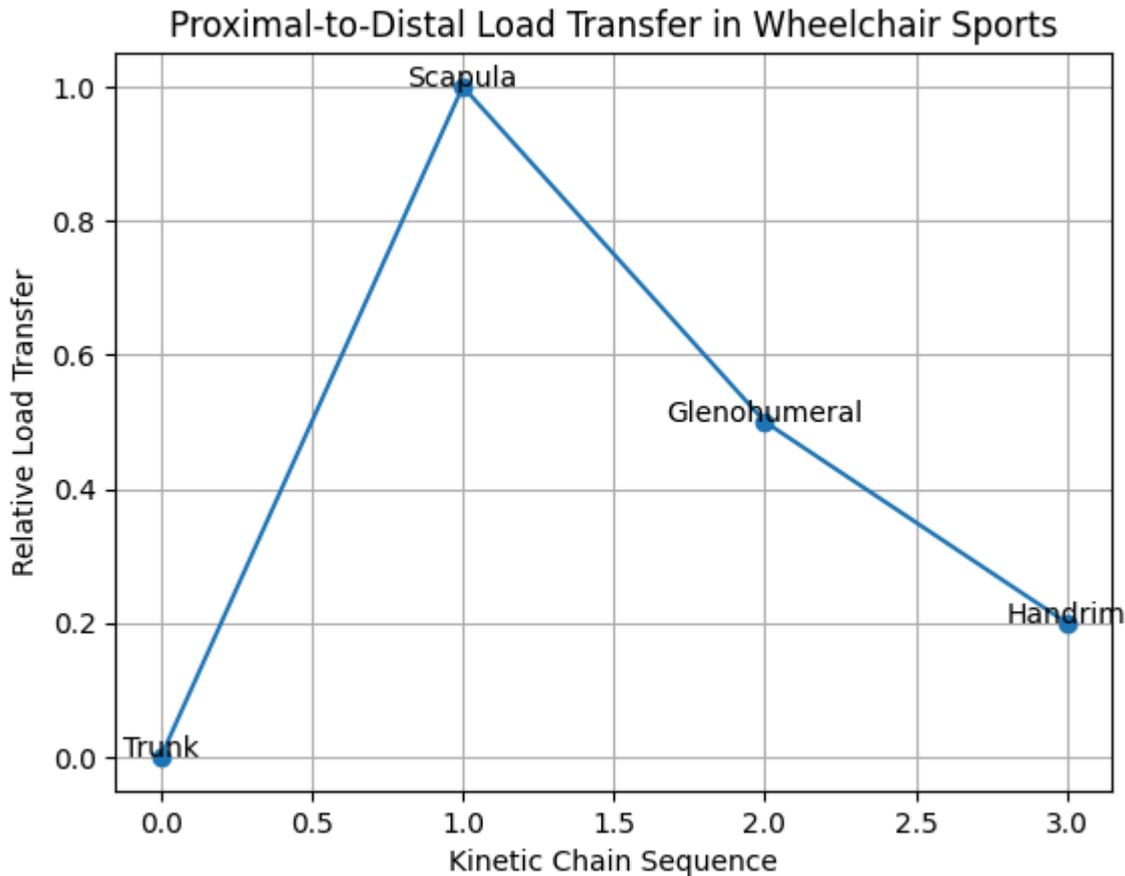


Figure 5. Proximal-to-distal load transfer model for wheelchair court sports (integrated framework).

4.1 Clinical Translation: Shoulder Preservation Strategies in Wheelchair Court Sports in

Clinical Translation: Shoulder Preservation Strategies in Wheelchair Court Sports

Findings from this review indicate that shoulder injury risk in elite wheelchair court sport athletes is driven primarily by kinetic chain inefficiencies rather than isolated glenohumeral strength deficits. Clinically, this supports a shift toward integrated training strategies emphasizing trunk modulation, scapulothoracic timing, and propulsion force regulation. Practitioners should prioritize seated trunk control exercises, scapular activation and sequencing drills, and load-monitoring strategies over isolated rotator cuff strengthening alone. Monitoring coordination breakdowns and fatigue thresholds may allow earlier intervention and improved long-term shoulder health in adaptive athletes.

5. Clinical and Performance Implications

- Extend beyond local strengthening to kinetic chain drills.
- Train trunk as load regulator via seated stability exercises.
- Target scapulothoracic timing with activation protocols.
- Monitor coordination over volume using wearables.

6. Limitations and Future Directions

Reliance on cross-sectional data limits causal inference, and heterogeneity in impairment level and sport-specific demands may influence the generalizability of findings. Future research should prioritize prospective and randomized controlled trials examining trunk-focused interventions, including whether modest improvements in trunk range of motion (e.g., 10–15%) can meaningfully reduce rotator cuff EMG demand (\approx 15–25%). Advances in wearable and AI-driven sensing technologies may further enable individualized load monitoring and precision-based injury prevention strategies in adaptive athletes.

7. Conclusion

Elite wheelchair court sport athletes are exposed to exceptionally high upper-extremity loading due to the combination of repetitive propulsion cycles and sport-specific demands such as rapid acceleration–deceleration, contact, and overhead reaching. This review supports the interpretation that shoulder pain and degenerative pathology in these athletes commonly emerge from disrupted kinetic chain load transfer rather than isolated deficits in local strength. When trunk contribution is reduced—whether by impairment level, fatigue, or technique—mechanical demands are shifted to the scapulothoracic and glenohumeral joints, increasing rotator cuff activation and joint compression forces. Similarly, scapular dyskinesis (delayed upward rotation, reduced posterior tilt) may reduce subacromial clearance and amplify tendon load during high-repetition sport actions. Importantly, peak torque measures alone appear to be weak predictors of pathology in many studies, whereas coordination and sequencing measures explain a larger portion of pain and injury variance. For practical translation, shoulder preservation programs should emphasize (1) trunk modulation and postural control, (2) scapular timing and endurance, (3) propulsion force-time quality (reducing abrupt loading and excessive push dominance), and (4) monitoring fatigue-related coordination breakdowns. Future research should prioritize sport-specific prospective studies and controlled interventions to establish causal pathways and determine optimal thresholds for clinical screening and load management.



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