Lower limb joint work during gait in persons with incomplete spinal cord injury

Minh T.N Truong[1], Emelie Butler Forslund[2,3], Åke Seiger[2,3], Elena M. Gutierrez Farewik[1,4]

[1]KTH MoveAbility, Dept. Engineering Mechanics, KTH Royal Institute of Technology, Stockholm, Sweden
[2]Aleris Rehab Station Stockholm, Stockholm, Sweden
[3]Dept. Neurobiology, Care Sciences and Society, Karolinska Institutet, Stockholm, Sweden
[4]Dept. Women's and Children's Health, Karolinska Institutet, Stockholm, Sweden
Email: minht@kth.se

Summary

This study investigates how neuromuscular weakness conditions influence compensatory strategies in individuals with incomplete spinal cord injury (iSCI) compared to non-disabled controls. Two iSCI groups with some plantarflexor weakness achieved comparable joint work and walking speed to controls. One iSCI subgroup with combined plantarflexor, hip extensor, and abductor weakness showed slower walking speed, lower positive ankle work, and lower negative knee work compared to controls. The most impaired iSCI subgroup exhibited slower walking speed, lower positive ankle, lower negative knee work, and lower negative hip work to controls. These findings demonstrate how varying levels of neuromuscular weakness, especially at the ankle and hip muscles, affect gait biomechanics after iSCI.

Introduction

Individuals with iSCI often exhibit diverse walking capabilities due to partial loss of their motor and/or sensory functions below the injury vertebral level. This study aims to gain better understanding of how compensatory strategies relate to varied neuromuscular weakness conditions following iSCI.

Methods

We recruited a cohort of 28 individuals with iSCI (AIS D; 18M/10F; age 57.8±12.6y) and 15 non-disabled control participants (10M/5F; age 53.1±13.2y). Participants with iSCI underwent physical assessment of lower extremity strength based on Manual Muscle Testing (MMT) grades. We performed 3D gait analysis on both groups (Vicon, CGM2.4 model), and extracted walking speed, kinematics and normalized joint power data. Positive and negative normalized joint work at each joint was computed as the integral of positive and negative, respectively, power over time. In a previous study [1], we identified six distinct iSCI subgroups through dynamic time warping and hierarchical agglomerative clustering. In this study, we analyzed four of these subgroups, i.e. those for whom we could collect kinetic data.

Results and Discussion

All iSCI subgroups achieved knee and hip positive work similar to controls (Figure 1). This finding aligns with their good-to-normal hip flexor, knee extensor, and knee flexor strength (MMT grades 4-5, Table 1). Despite weak plantarflexors, Groups I and II achieved joint work and walking speed similar to control. Group III displayed similar plantarflexor weakness to Group II, but with more hip abductor weakness. This combination of muscle weakness conditions resulted in significantly slower walking speed and lower positive ankle work and negative knee work compared to controls. Group IV, with the most severe plantarflexors and hip (extensor and adductor) weakness, demonstrated significantly slower walking speed, lower positive ankle work, negative knee work, and negative hip work compared to controls.

Table 1: MMT grades of the iSCI subgroups. The grades are presented as Median(Q1,Q3).

Group	I	II	III	IV
	n_{legs} = 9	n_{legs} = 13	n_{legs} = 11	n_{legs} = 10
Hip Ext	5(4,5)	4(4,5)	4(4,5)	3.5(2,4)
Hip Abd	5(4,5)	5(4,5)	4(3,5)	4(3,5)
Hip Add	5(4,5)	5(4,5)	5(4,5)	3.5(3,5)
Ankle Plan	4(4,5)	3(2,4)	3(2,5)	2(2,2)

All participants had MMT grade 4-5 in hip flexors, knee extensors, knee flexors, and ankle dorsiflexors.

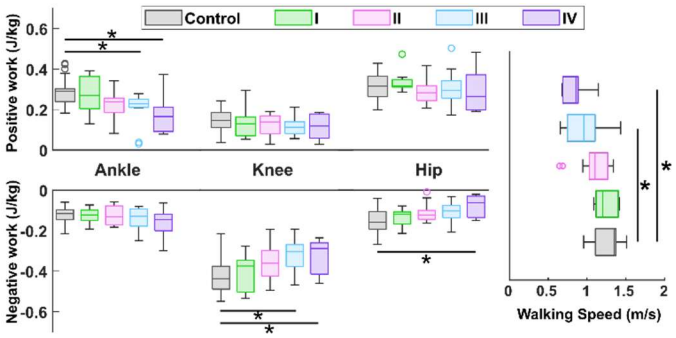

Figure 1: Left: Ankle, knee, and hip joint work during gait in iSCI subgroups compared to controls; Right: walking speed. * denotes significant difference ($p < 0.05$) between the iSCI subgroup and controls.

Conclusions

Isolated plantarflexor weakness after iSCI had minimal impact on ankle work and gait speed. However, concurrent weakness in plantarflexors and hip abductors significantly reduced both ankle propulsion work and knee power absorption. More severe plantarflexor weakness, particularly with additional hip extensor and adductor weakness, further compromised hip energy storage. People with iSCI compensated for these weaknesses by walking more slowly.

Acknowledgments

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References

[1] Minh Truong et al. (2024). *Gait Posture*, **113**: 224-225.