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Case Report

Impact of 3D-Printed Technology on Functional Performance in an Individual with C2 Spinal Cord Injury: A Case Report

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Abstract

This case report describes the use of a 3D-printed wheelchair joystick to improve functional performance in an individual with incomplete traumatic spinal cord injury at C2. A 29-year-old man presented with complete tetraplegia and no residual upper extremity function following a traffic accident, rendering him unable to operate manual or electric wheelchairs. To address this limitation, a joystick adapted for residual shoulder movements was developed using fused deposition modeling with polylactic acid material. After training, the patient achieved proficiency in maneuvering the wheelchair, as assessed with the Functional Independence Measure, enabling safe navigation and increased engagement in daily activities. This case illustrates how 3D-printed assistive devices can enhance functional autonomy and community participation in individuals with high cervical spinal cord injury.

Keywords: Wheelchair joystick, C2 spinal cord injury, Functional Independence Measure, 3D printing, FDM.

Introduction

Spinal cord injuries (SCIs) significantly affect physical and functional abilities, limiting independence in mobility, self-care, and daily occupations (Abu-Baker, Al-Zyoud, & Alshraifeen, 2021; Foy et al., 2011; Arsh, Anwar, Zeb, & Ilyas, 2020; Keusen, Vuilliomenet, Friedli, & Widmer, 2023). These challenges are especially pronounced in individuals with high-level cervical injuries, such as C2, where the absence of upper extremity function severely restricts wheelchair use and community participation. Conventional assistive devices often fail to meet the highly specific needs of this population. Recent advances in 3D printing have enabled the development of customized, low-

cost assistive technologies tailored to individual requirements (Hunzeker & Ozelie, 2021). In rehabilitation, such devices have been shown to support independence, reduce caregiver burden, and improve quality of life (Christiansen, 2010). This case report describes the application of a 3D-printed wheelchair joystick, adapted for shoulder control, to improve functional performance in an individual with incomplete traumatic SCI at C2, as classified by the American Spinal Injury Association Impairment Scale (ASIA AIS).

Case presentation

A 28-year-old man met with a traffic accident in 2017 and experienced a C2 vertebral fracture. As per the International Standards for Neurological Classification of Spinal Cord Injury, the patient was diagnosed with ASIA C C2 SCI. He underwent four rehabilitation admissions: three local and one overseas. Additionally, an intrathecal baclofen pump was inserted in 2018 to manage spasticity. In 2022, he was admitted to our facility for equipment provision.

Social History

The patient lived in the Eastern province of Saudi Arabia in a two-story house. After the injury, his room was moved to the ground floor. He lived with his mother and sisters, one of whom served as the primary caregiver. He had a medical bed with an air mattress and a manual reclining wheelchair. At the time of the injury, he was a university student but could not complete his studies thereafter.

Physical examination and assessment

Mental status

The patient was conscious, alert, and could follow complex instructions. He was oriented toward time, place, and person.

Sensation

Superficial sensation was impaired below the C2 dermatomal level, whereas proprioception was intact in the upper and lower limbs.

Muscle tone

Muscle tone was assessed using the modified Ashworth scale (Biering-Sørensen, Nielsen, & Klinge, 2006) (Table 1). The results of the assessments are as follows. Upper limbs: 1/4 in the elbow extensors, 1+/4 in the pronators, 1+/4 in the wrist flexors, 1+/4 in the right finger flexors, and 1/4 in the left finger flexors. Lower limbs: 2/4 in the bilateral hip and knee extensors, 1/4 in the bilateral hip adductors, knee flexors, and ankle plantar flexors with the bilateral ankle clonus. The range of motions of all joints of the upper and lower limbs were within normal ranges, except for a mild bilateral limitation in ankle dorsiflexion.

Muscle power

Muscle power was assessed using the grading system described by Daniels and Worthingham (Brown, Hislop, & Avers, 2013) (Table 2), with scores ranging from 0 to 5, representing no muscle activity and normal response, respectively. Tables 3, 4, 5, and 6 show the details of the range of motions and muscle power assessments.

Fine motor and hand functions

The patient could not perform fine or gross hand movements.

Functional evaluation

The patient was unable to perform activities independently. Functional Independence Measure (UDSMR, 2018) was used to evaluate functional ability. Table 7 summarizes the

functional status of the patient.

Admission goals

The main goal of admission was to reduce the burden of care on family members/caregivers through appropriate medical equipment, proper education, and training. The patient's primary goal was to achieve independent mobility using an electric wheelchair.

Rehabilitation course

During admission, the patient received 1 hour of physical and occupational therapy each, five days a week for 7 weeks. Physical therapy focused on maintaining the available range of motions in the lower limbs and preventing contractures and pressure injuries, as well as providing relevant education to family/caregivers. Occupational therapy primarily aimed to improve upper limb muscle power to facilitate the use of a tilt-in-space electric wheelchair. Owing to severe hand grip weakness, the subject could not use a standard wheelchair joystick. The use of an off-the-shelf modified joystick was attempted but to no avail. Finally, a 3D-printed joystick was used to achieve better control. He could move the electric wheelchair forward/backward, turn right/left, and start/stop without assistance. Assistance was required only to turn on the wheelchair and reach the joystick. During admission, he was provided with a tilt-in-space electric wheelchair with a 3D printed joystick, a high-profile air cushion, a hoist, a tilt-in-space commode, an air mattress, a transfer board, a custom-made wrist-hand orthosis, and a non-weight-bearing ankle-foot orthosis.

Table 1. Modified Ashworth scale

Grade	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, manifesting as a catch and release or by minimal resistance at the end of ROM* when the affected part(s) is moved in flexion or extension.
1+	Slight increase in muscle tone, manifesting as a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM
2	Marked increase in muscle tone throughout most of the ROM; however, the affected part(s) is easily moved
3	Considerable increase in muscle tone; however, passive movement is difficult
4	The affected part(s) is rigid in flexion or extension
*ROM: Range of motion	

Table 2. Daniels and Worthingham's Muscle Testing Grading System

Grade	Description
5 (Normal)	Ability to complete a full range of motion against gravity and maximal resistance
4 (Good)	Ability to complete a full range of motion against gravity and moderate resistance
3+ (Fair+)	Ability to complete a full range of motion against gravity and mild resistance
3 (Fair)	Ability to complete a full range of motion against gravity
2 (Poor)	Ability to complete a full range of motion with gravity eliminated
2- (Poor-)	Ability to complete partial range of motion with gravity eliminated
1 (Trace)	Visible or palpable contractions only
0 (Zero)	No visible or palpable contractions

Table 3. Muscle power chart of the upper limbs

Joint	Movement	Right	Left
Shoulder	Flexion	2-	2-
	Extensions	2-	2-
	Abduction	2-	2-
	Adduction	2-	2-
	Internal rotation	2-	2-
	External rotation	2-	2-
Elbow	Flexion	2-	2-
	Extension	2-	2-
	Supination	2-	2-
	Pronation	2-	2-
Wrist	Flexion	0	1
	Extension	2-	2
	Ulnar Deviation	2-	2-
	Radial Deviation	2-	2-
Hand	Metacarpal flexion	2-	2-
	Metacarpal extension	2-	2-
	Proximal Finger Interphalangeal Flexion	2-	2-
	Distal Finger Interphalangeal Flexion	2-	2-
	Finger Adduction	2-	2-
	Finger Abduction	2-	2-
	Thumb Metacarpophalangeal Flexion	2-	2-
	Thumb Metacarpophalangeal Extension	2-	2-
	Thumb Interphalangeal Flexion	2-	2-
	Thumb Interphalangeal Extension	2-	2-
	Thumb Abduction	2-	2-

Table 4. Passive range of motions of the upper limbs

Joint	Movement	Right	Left
Shoulder	Flexion	WNL*	WNL
	Extensions	WNL	WNL
	Abduction	WNL	WNL
	Adduction	WNL	WNL
	Internal rotation	WNL	WNL
	External rotation	WNL	WNL
Elbow	Flexion	WNL	WNL
	Extension	WNL	WNL
	Supination	WNL	WNL
	Pronation	WNL	WNL
Wrist	Flexion	WNL	WNL
	Extension	WNL	WNL
	Ulnar Deviation	WNL	WNL
	Radial Deviation	WNL	WNL
Hand	Metacarpal flexion	WNL	WNL
	Metacarpal extension	WNL	WNL

	Proximal Finger Interphalangeal Flexion	WNL	WNL
	Distal Finger Interphalangeal Flexion	WNL	WNL
	Finger Adduction	WNL	WNL
	Finger Abduction	WNL	WNL
	Thumb Metacarpophalangeal Flexion	WNL	WNL
	Thumb Metacarpophalangeal Extension	WNL	WNL
	Thumb Interphalangeal Flexion	WNL	WNL
	Thumb Interphalangeal Extension	WNL	WNL
	Thumb Abduction	WNL	WNL

WNL: Within normal limits

Table 5. Muscle power chart of the lower limbs

Joint	**Movement**	**Right**	**Left**
Hip	Flexion	0	0
	Extensions	0	0
	Abduction	0	0
	Adduction	1	1
	Internal rotation	0	0
	External rotation	0	0
Knee	Flexion	0	1
	Extension	2-	2-
Ankle	Dorsiflexion	0	1
	Plantarflexion	2-	2-

Table 6. Passive range of motion of the lower limbs

Joint	**Movement**	**Right**	**Left**
Hip	Flexion	WNL	WNL
	Extensions	WNL	WNL
	Abduction	WNL	WNL
	Adduction	WNL	WNL
	Internal rotation	WNL	WNL
	External rotation	WNL	WNL
Knee	Flexion	WNL	WNL
	Extension	WNL	WNL
Ankle	Dorsiflexion	10 degrees of plantarflexion	10 degrees of plantarflexion
	Plantarflexion	10-45	10-45

WNL: Within normal limits

Table 7. Functional Independence Measure scores

Task	Admission	Discharge
Eating	1	1
Grooming	1	1
Bathing	1	1
Upper body dressing	1	1
Lower body dressing	1	1
Toileting	1	1

Bladder management	1	1
Bowel management	1	1
Toilet transfer	1	1
Bathtub transfer	1	1
Wheelchair transfer	1	1
Locomotion	1	5
Stairs	1	1
Comprehension	7	7
Expression	7	7
Memory	7	7
Problem-solving	7	7
Social interaction	7	7

Ethical considerations

This study was approved by the Institutional Review Board (IRB) of King Fahad Medical City, Riyadh (RE: 23-096). Written informed consent for participation and publication of anonymized clinical details and images was obtained from the patient.

Discussion

In light of the concept of occupational alienation within the realm of occupational justice, as stated by Christiansen and Townsend, it becomes apparent that experiences devoid of meaning or purpose, marked by feelings of isolation, powerlessness, frustration, loss of control, or estrangement from society or self, stem from engagement in occupations that fail to fulfill inner needs related to meaning and purpose (Christiansen, 2010). Stadnyk et al. further contend that injustice arises when societies prioritize the enhancement of physical and mental well-being without providing adequate resources to facilitate individuals' engagement in activities essential to them and others (Stadnyk, Townsend, & Wilcock, 2010).

The correlation between the extent of SCI and the degree of independence in performing activities of daily living among patients with complete motor lesions, particularly those with cervical lesions, is well-established (Scivoletto, 2022) and comprehensively delineated in the clinical guidelines published by the Consortium for Spinal Cord Medicine (Table 8). Generally, individuals with cervical lesions above C5 can achieve independence in wheelchair propulsion through head, chin, or breath-controlled mechanisms (Consortium for Spinal Cord Medicine, 2000). However, conventional assistive devices incur considerable expenses, often totaling hundreds of dollars. For instance, the Tecla-e sip-and-puff switch kit is priced at $729.00, exclusive of shipping fees and expenditures associated with staff training (tecla, 2024). In contrast, the production cost of a 3D-printed joystick (figure 1) is significantly lower, amounting to less than $5.00 when utilizing polylactic acid material with 100% infill and requiring approximately 5 h of printing time (Hojin, 2019). Moreover, our patient expressed a distinct preference for handheld joysticks over traditional control mechanisms. Taking into account patient choices empowers them to assert their preferences and maintain a sense of control over their lives, contributing to enhanced coping mechanisms and overall improvement in quality of life (van Leeuwen, Kraaijeveld, Lindeman, & Post, 2012).

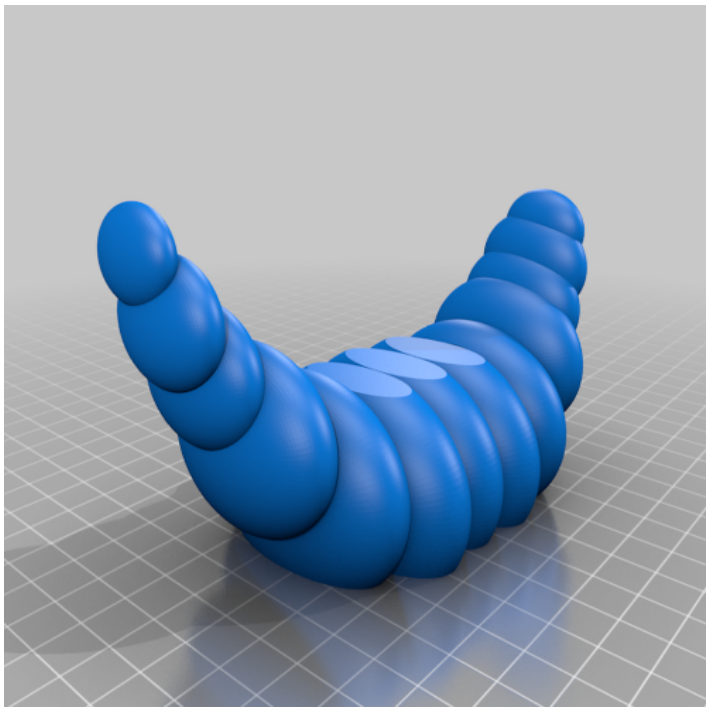

Figure 1. Hojin (2019) joystick design

In recent years, 3D printing has emerged as a prominent technology in the field of medical rehabilitation, particularly in the fabrication of orthotic devices, including knee, ankle-foot, wrist, hand, and foot orthoses. For instance, Chae et al. demonstrated improvements in hand function and ambulation in three individuals with peripheral nerve injuries following the implementation of 3D-printed orthoses (Chae et al., 2020). Our findings align closely with those reported by Shin et al., who observed improved wheelchair mobility after the application of a custom 3D-printed joystick in four individuals with severe quadriplegia resulting from cervical SCIs; Three patients used joystick-controlled wheelchairs, whereas the fourth patient operated a wheelchair using chin control (Shin et al., 2021). Compared with the participants described by Shin et al., our patient faced challenges in operating an electric wheelchair because of the inability to effectively utilize a conventional or commercially available modified joystick. Consequently, the application of 3D printing technology became imperative to engineer a customized joystick tailored to accommodate the specific features of his hand dysfunction.

A higher degree of SCI is correlated with increased secondary health complications, often resulting in constrained participation and limited outdoor mobility, leading to a sedentary indoor lifestyle (Alve & Bontje, 2019). Our patient expressed a desire to utilize his hand for wheelchair control rather than resorting to sip-and-puff control. Given the high level of injury and limited muscle power, designing and executing movements safely presented theoretical challenges. Our intervention was based on the residual movement that had persisted following the injury, characterized as an atypical SCI (C2 ASIA C).

Our study demonstrated the efficacy of a 3D-printed joystick for electric wheelchairs in allowing easier mobility and satisfaction among individuals with decreased hand function following high-level SCIs. Our study has several strengths, including the introduction of cost-effective and up-to-date equipment that can be tailored to individual patient needs and clinical presentations. This customization encompassed patient-specific adjustments, ensuring alignment with patient requirements, satisfaction, and goals, as opposed to standard alternatives such as sip-and-puff control. The relevant literature in the medical rehabilitation field for this specific demographic, particularly those with high SCI, has primarily focused on assessing quality of life indicators through measures such as mental well-being, life satisfaction, spasticity, pain, and pressure injuries.

Our study has some limitations, notably the scarcity of studies exploring the application of 3D printing technology among individuals with high cervical SCI. This study is limited by its single-case design, which restricts the generalizability of the findings to broader populations with high-level spinal cord injury. The absence of long-term follow-

up limits understanding of the durability and sustained impact of the 3D-printed joystick on functional outcomes. In addition, outcome assessment may have been influenced by observer bias, as clinicians were aware of the intervention. Finally, no standardized patient-reported measures of satisfaction or quality of life were included, which may have provided additional insight into the broader impact of the intervention (Smith, Doe, & Lee, 2020).

Table 8. Expected functional outcomes for patients with complete lesions at different cervical levels

	C1-C3	C4	C5	C6	C7-C8
Respiratory	Ventilator dependent	May be able to breathe without a ventilator	Low endurance and vital capacity secondary to paralysis of intercostals; may require assistance to clear secretions	Low endurance and vital capacity secondary to paralysis of intercostals; may require assistance to clear secretions	Low endurance and vital capacity secondary to paralysis of intercostals; may require assistance to clear secretions
Bowel	Total assistance	Total assistance	Total assistance	Some to total assistance	Some to total assistance
Bladder	Total assistance	Total assistance	Total assistance	Some to total assistance with equipment	Independent to some assistance
Bed mobility	Total assistance	Total assistance	Some assistance	Some assistance	Independent to some assistance
Bed/wheelchair transfers	Total assistance	Total assistance	Total assistance	Level: Some assistance to independent Uneven: Some to total assistance	Level: Independent Uneven: Independent to some assistance
Pressure relief/ positioning	Total assistance; may be independent with equipment	Total assistance; may be independent with equipment	Total assistance; may be independent with equipment	Independent with equipment and/or adapted techniques	Independent
Eating	Total assistance	Total assistance	Total assistance for setup, then independent eating with equipment	Independent with or without equipment; except cutting, which requires total assistance	Independent
Dressing	Total assistance	Total assistance	Lower limbs: Total assistance Upper limbs: Some assistance	Independent upper limbs; some to total assistance for lower limbs	Independent upper limbs; Independent to some assistance for lower limbs
Grooming	Total assistance	Total assistance	Some to total assistance	Some assistance to independent with equipment	Independent
Bathing	Total assistance	Total assistance	Total assistance	Lower body: Total assistance Upper body: Some to total assistance	Lower body: some assistance to independent Upper body: Independent

Wheelchair propulsion	Power: Independent with head, chin, or breath control Manual: Total assistance	Power: Independent with head, chin, or breath control Manual: Total assistance	Power: Independent with arm drive control Manual: Independent to some assistance for indoors on non-carpet, level surface; some to total assistance for outdoors	Power: Independent with standard arm drive for all surfaces Manual: Independent for indoors; some to total assistance for outdoors	Manual: Independent for all indoor surfaces and level outdoor terrain; some assistance for uneven terrain

Conclusion

This case highlights the value of innovative rehabilitation approaches tailored to the unique needs of individuals with high-level spinal cord injuries. The use of 3D printing to customize a wheelchair joystick demonstrated the potential to enhance mobility, independence, and quality of life in a patient with an incomplete C2 injury. The findings underscore the importance of patient-centered care, where assistive devices are adapted to align with individual goals and preferences, thereby supporting empowerment and functional participation. While this report contributes to the growing evidence for 3D-printed technologies in rehabilitation, further studies with larger samples and long-term follow-up are needed to establish their broader applicability and effectiveness.

Future Recommendations

Future research should explore the application of 3D-printed assistive technologies in larger and more diverse samples of individuals with high cervical spinal cord injuries. Studies incorporating longer follow-up periods are needed to evaluate the durability, usability, and safety of such devices in daily life. Incorporating standardized patient-reported outcome measures, such as quality of life and satisfaction scales, would strengthen the evidence base. Cost-effectiveness analyses and cross-cultural studies could further inform clinical adoption, ensuring that such technologies are both accessible and tailored to individual needs in real-world rehabilitation settings.

Author Contributions

All authors significantly contributed to the work reported, including conception, study design, execution, data acquisition, analysis, and interpretation. They actively participated in drafting, revising, or critically reviewing the manuscript, provided final approval of the version to be published, agreed on the journal submission, and accepted accountability for all aspects of the work.

Data Availability Statement

The authors will transparently provide the primary data underpinning the findings or conclusions of this article, without any unjustified reluctance. If need from editorial team.

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