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The positive role of physical therapy and appropriate technology in the reduction of bone mineral density loss associated with complete spinal cord injury: A case report

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Abstract

While no single method effectively prevents bone loss after spinal cord injury (SCI), consistent participation in activity-based therapies can help reduce it in individuals with chronic complete SCI. This case report presents the results of multiple dual-energy X-ray absorptiometry scans conducted over 14 years, highlighting changes in bone mineral density (BMD). The individual studied maintained a healthy lifestyle, preventing secondary complications associated with SCI. The focus is on the participant's engagement in various therapies, including functional electrical stimulation, lower-extremity cycling, and walking with a robotic exoskeleton. Remarkably, the findings indicate that, rather than losing BMD, this individual not only maintained but, in some areas, also even increased their BMD in the lower extremities. This observation contradicts the expected trend for individuals with chronic complete SCI, suggesting that activity-based therapies may yield positive outcomes.

Keywords

Spinal cord injury, bone mineral density, activity-based therapy, physical therapy, technology

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Introduction

Traumatic spinal cord injury (SCI) occurs at an estimated rate of 18,000 new cases annually, leading to physical impairments and numerous secondary complications.[1] Dramatic bone mineral density (BMD) loss occurs over the first year postinjury and continues declining for over two decades.[2–4] Individuals with SCI have twice the risk of developing fractures due to the decrease in overall strength of the bones compared to healthy controls.[5,6] Lower limb fractures not only impact the ability to perform daily functional tasks, they often lead to hospitalization, medical complications, and mortality.[6,7]

Physical therapy interventions implemented over the years to help reduce the loss of BMD after SCI include standing programs, functional electrical stimulation (FES), body weight supported treadmill (BWST) ambulation, activity-based therapy (ABT), vibration, resistance exercises, and more recently use of exoskeletons for ambulation. Although some of these interventions have shown an ability to impact bone loss, a definitive intervention for preventing bone loss after SCI remains elusive.[2,8,9] A recent study suggests that 24 weeks (total of 72 sessions) of walking with an overground robotic exoskeleton prevents the progressive decline of BMD in chronic incomplete SCI.[10]

While there is no single protocol demonstrating minimum frequency, intensity, and duration of an intervention that has conclusively proven to prevent bone loss after SCI, a combination of ABT interventions (FES, BWST, exoskeleton-assisted walking), coupled with consistent participation over time, shows promise in reducing bone loss. This case study presents an individual with chronic complete SCI who defies the anticipated trend of BMD loss, emphasizing the potential impact of ABT interventions.

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Table 1. Subject BMD and able-bodied BMD reference data.

BMD (g/cm²)	FN	TH	DF	PT
Able-bodied				
Looker et al.[12]				
30–40 yo	0.884 ± 0.127			
40–50 yo	0.871 ± 0.121			
Kim et al.[11]	0.969 ± 0.113	0.979 ± 0.109		
Cirnigliaro et al.[4]	1.037 ± 0.203	1.023 ± 0.131	1.037 ± 0.203	1.320 ± 0.249
Subject TSI (age)				
3 y (31 yo)	0.783	NT	NT	NT
10 y (38 yo)	0.718	0.833	1.012	0.904
13 y (41 yo)	0.747	0.898	0.926	0.901
16 y (44 yo)	0.758	0.875	0.948	0.907
17 y (45 yo)	0.775	0.868	0.941	0.924

TSI: time since injury; yo: years old; BMD: bone mineral density (measured in g/cm²); FN: femoral neck; TH: total hip; DF: distal femur; PT: proximal tibia.

Case presentation

A 28-year-old male sustained a complete SCI (AIS grade A) at T4 due to a vehicle versus farm equipment accident in 2005. He received inpatient rehabilitation followed by outpatient aquatic therapy for 6 months. Living in a small town 2 hours from the nearest metropolitan city and an hour from the nearest large town impacted access and frequency of therapy participation. He took Oxybutynin, Myrbetriq, and Bisacodyl for bladder and bowel management. He did not take any vitamins or oral medications for bone loss prevention postinjury or over the course of this case study investigation. Over the course of the next 3 years, he progressively returned to work full-time, limiting his availability to participate in ABT outside the home. This individual has clonus at bilateral ankles but no lower limb spasticity.

After completion of initial inpatient and outpatient rehabilitation services, where he received standard-of-care physical therapy interventions, he engaged in 16 ABT sessions walking in the Lokomat (Hocoma AG, Volketswil, Switzerland), a robotic gait device with body weight support over a treadmill, over that year (2008). Initial dual-energy X-ray absorptiometry (DEXA) scan in 2008, 1 month shy of 3 years postinjury, demonstrated a lower BMD score than that of able-bodied references.[4,11,12] At this time, only the left femoral neck (FN) was assessed (0.783 g/cm²), demonstrating lower than average BMD for individuals with SCI for 1–5 years (0.873 ± 0.141 g/cm²).[4] However, his Z-score at the FN (−0.9) was higher than the average of gender and age-matched individuals (−1.37 ± 1.01) with SCI between 1 and 5 years.[4] Table 1 presents the subject BMD and the able-bodied BMD reference data. Table 2 presents a summary of subject and SCI BMD scores, Z-scores, and T-scores.

In 2009, he had 7 Lokomat sessions but no interventions in 2010. After dialogue with his employer and insurance company, he began making the 4-h round-trip journey into the city to participate in outpatient physical therapy as often as he could, within the confines of the drive and his job. In 2011 and 2012, he received Lokomat and FES Cycling. The following year, he participated in BWST along with Lokomat and FES Cycling, and in 2014, he continued with Lokomat and FES Cycling. Between 2008 and 2015, he received 197 ABT interventions, averaging 28 sessions yearly.

In 2015, 10 years postinjury, a DEXA scan was completed on the left FN, left total hip (TH), bilateral distal femurs (DF), and proximal tibias (PT). The FN (0.718 g/cm²) remained lower than average for individuals with SCI 6–10 years (0.874 g/cm²).[4] Interestingly, his Z-score at FN (−1.2) remains higher than age and gender-matched individuals with SCI 6–10 years (−1.34).[4] Although BMD at FN is low, the TH (0.833 g/cm²) is higher than individuals with SCI 6–10 years (0.827 g/cm²).[4] DF (1.012 g/cm²) is greater than SCI 6–10 years (0.838 g/cm²), but PT (0.904 g/cm²) is lower than SCI 6–10 years (0.958 g/cm²).[4] Due to previous DEXA scans not including TH, DF, and PT, we consider the 10-year DEXA scan as our baseline for this case study.

Beginning in 2015, overground robotic exoskeletons were added as part of his ABT interventions. In 2015, 2016, and 2017 he received Lokomat, FES Cycling, and ReWalk (ReWalk Robotics Ltd.; DBA Lifeward, Marlborough, MA, USA) overground robotic walking sessions, in addition to 1 Indego (Ekso Bionics, Macedonia, OH, USA) overground exoskeleton walking session, for a total of 166 sessions or an average of 55 sessions per year. In 2018, at 13 years postinjury, his DEXA scan revealed that although his BMD had decreased at DF and L PT from his previous scan, his BMD at all sites is now above average for individuals with SCI 11–20 years.[4]

He began participating in research studies for the use of lower extremity overground robotic exoskeletons in 2018, completing 1 session in ReWalk, 12 in Ekso (Ekso Bionics, San Rafael, CA, USA), 11 in Rex (Rex Bionics, Wairau Valley Auckland, New Zealand), and 13 in Indego for a total of 37 ABT interventions in 2018. In 2019, he successfully obtained insurance approval for a home FES cycle. His primary ABT sessions over 2019 and 2020 were Lokomat and

Table 2. Summary of subject and SCI BMD scores, *Z*-scores, and *T*-scores.

Year	2008	2015	2018	2021	2022
TSI (age)	3 y (31 yo)	10 y (38 yo)	13 y (41 yo)	16 y (44 yo)	17 y (45 yo)
BMD FN					
Subject	0.783	0.718	0.747	0.758	0.775
SCI Avg	0.873 ± 0.141	0.874 ± 0.179	0.72 ± 0.089	0.72 ± 0.089	0.72 ± 0.089
BMD TH					
Subject	NT	0.833	0.898	0.875	0.868
SCI Avg	0.826 ± 0.142	0.827 ± 0.168	0.662 ± 0.119	0.662 ± 0.119	0.662 ± 0.119
BMD DF					
Subject	NT	1.012	0.926	0.948	0.941
SCI Avg	0.886 ± 0.169	0.838 ± 0.168	0.714 ± 0.148	0.714 ± 0.148	0.714 ± 0.148
BMD PT					
Subject	NT	0.904	0.901	0.907	0.924
SCI Avg	1.084 ± 0.259	0.958 ± 0.205	0.781 ± 0.137	0.781 ± 0.137	0.781 ± 0.137
Z-score FN					
Subject	−0.9	−1.2	−0.85	−0.95	−0.55
SCI Avg	−1.37 ± 1.01	−1.34 ± 1.64	−2.00 ± 1.40	−2.00 ± 1.40	−2.00 ± 1.40
T-score FN					
Subject	−1.08	−1.6	−1.35	−1.25	−1.15
SCI Avg	−1.3 ± 1.07	−1.27 ± 1.29	−2.44 ± 0.70	−2.44 ± 0.70	−2.44 ± 0.70
T-score TH					
Subject	NT	−1.3	−0.9	−1.05	−1.1
SCI Avg	−1.54 ± 1.18	−1.58 ± 1.29	−2.88 ± 0.82	−2.88 ± 0.82	−2.88 ± 0.82

TSI: time since injury; BMD: bone mineral density (measured in g/cm^2); FN: femoral neck; TH: total hip; DF: distal femur; PT: proximal tibia; SCI: spinal cord injury; SCI Avg: reference data from Cirnigliaro et al.[4] based on time since SCI.

FES Cycling. Between 2018 and 2020, he received 462 sessions, averaging 154 sessions per year. With the increase in frequency, we see that in 2021, 16 years postinjury, half of his BMD scores have decreased (B DF, L PT), and half have increased (L FN, L TH, R PT), but all sites remain above average for individuals with SCI 11–20 years.[4]

In 2021, he began training with the Indego in preparation for receiving his personal device. Throughout the year, ABT interventions were more spread out across Lokomat, FES, and Indego, with a total of 156 sessions for the year. Results of his 2022 DEXA scan demonstrate that half of his LE sites had increased BMD (B FN, R DF, L PT), one site remained the same (R TH), and three decreased in BMD (L TH, L DF, R PT). His BMD levels remain above the expected range for individuals with SCI 11–20 years.[4]

Discussion

This case study challenges the expected trajectory demonstrating an individual 17 years postcomplete SCI who is beating the odds. Currently, there is not enough information to provide clinical recommendations. It's exciting to see the emergence of tools, such as wearable robotic exoskeletons and FES cycling, that can be used in therapy and at home to help individuals with complete SCI stand and walk. However, a significant challenge is the limited evidence guiding us on the minimum intensity, frequency, and duration required for clinically meaningful changes. While studies and patients indicate that these methods are feasible, they require effort and commitment; it is not a one-time activity or intervention. From this retrospective care report, we believe that a combination of electrical stimulation and load-bearing, overground stepping is most likely to yield a positive impact.

After the injury, the subject has not developed any lower limb fragility fractures but he has demonstrated above-average BMD compared to other individuals with SCI at the same time since injury and improvements in his BMD scores. We believe this may be attributed to the consistent participation in ABT over time and the increasing frequency of participation that has aided in reducing the dramatic loss of BMD in the lower extremities (Figure 1).

Although evidence on the efficacy of ABT in preventing or reducing BMD loss after SCI remains inconclusive, certain studies highlight its potential benefits. Shackleton et al. found that hip BMD was maintained over 24 weeks when individuals with SCI ambulated three times a week in the Ekso exoskeleton.[10] Karelis et al. also found that walking in Ekso three times a week for 6 weeks increased BMD at the tibia in chronic complete SCI.[13] The lack of established guidelines or consensus on the frequency and type of weight-bearing activities to maintain or reduce loss of BMD after SCI underscores the significance of individualized approaches, as demonstrated by this case.

This participant, a model patient with a SCI, has consistently adhered to a home exercise program, regularly using a standing

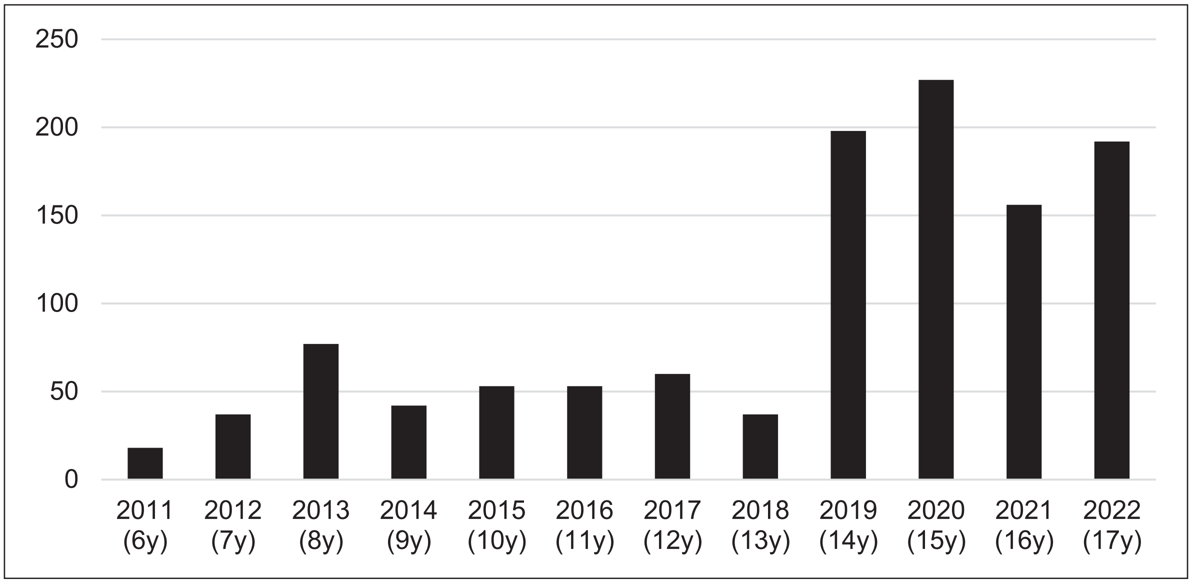

Figure 1. The number of ABT sessions the subject completed from 2011 (time since injury: 6 years) to 2022 (time since injury: 13 years).
ABT: activity-based therapy.

frame and advocating for insurance coverage of essential physical therapy and equipment. Despite initial insurance challenges, he sought out ABT opportunities, including research studies with lower extremity exoskeletons and wellness programs, while educating himself on advancements in rehabilitation technology. His dedication has contributed to favorable BMD scores in his DEXA scans, and he has never been re-hospitalized or developed pressure sores—common complications of SCI. Unlike many of his peers, he has maintained gainful employment, supported by strong family assistance for his health activities. However, a limitation of this report is the lack of follow-up evaluations after the retrospective review is completed.

Conclusion

This exemplary case illustrates the potential of consistent and targeted ABT interventions in defying the anticipated BMD loss in chronic complete SCI. The individual's commitment to therapy, advocacy for resources, and engagement in technological advances highlight the importance of a holistic approach in SCI management. Despite challenges, this case offers hope for individuals with SCI to maintain healthy lifestyles, potentially reducing BMD loss and fracture risk through ABT and technology use.

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Author contributions

M.K. compiled and analyzed the data and drafted the manuscript. S.-H.C. analyzed the data and reviewed and revised the manuscript.

Declaration of conflicting interests

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Ethical approval

Ethical approval to report this case was obtained from the Committee For the Protection of Human Subjects, The University of Texas Health Science Center at Houston (HSC-MS-15-0923).

Informed consent

The participant provided written consent to participate in the primary study and verbal consent to participate in data collection for the case study.

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