

ANALYSIS OF HEART RATE VARIABILITY DURING HOSPITALIZATION IN PATIENTS WITH SPINAL CORD INJURY

NATHÁLIA MOURA GONÇALVES¹, GIULLIANO GARDENGHI², LETÍCIA DE SOUZA PEREIRA³, FRANCISCO TIAGO OLIVEIRA DE OLIVEIRA⁴,
GRAZIELLA FRANÇA BERNARDELLI CIPRIANO⁵, ERIKA LETÍCIA GOMES NUNES⁶

1. Hospital de Urgências de Goiás Dr. Valdemiro Cruz (HUGO) Goiânia/GO, Brazil.
2. Hospital ENCORE Aparecida de Goiânia/GO, Brazil.
3. Superintendência da Escola de Saúde de Goiás, Goiânia/GO, Brazil.
4. Escola Bahiana de Medicina e Saúde Pública Salvador/BA, Brazil.
5. Universidade de Brasília Brasília/DF, Brazil.
6. Hospital e Maternidade Municipal Santa Ana São Paulo/SP, Brazil.

ABSTRACT

Introduction: Spinal cord injury (SCI), especially at cervical and upper thoracic levels, impairs cardiovascular autonomic regulation, resulting in changes in heart rate (HR) and responses to postural stimuli. Heart rate variability (HRV) is a noninvasive method used to assess this modulation.

Objective: To analyze HRV in adult patients with spinal cord injury during hospital hospitalization, comparing individuals with injuries above and below the T5 level in different body positions.

Methods: This was a cross-sectional observational study conducted in the wards of an Emergency Hospital in Goiás, Brazil, including individuals aged ≥ 18 years of both sexes diagnosed with spinal cord injury. HRV was recorded using a Polar H10 heart rate monitor in the supine position at 0° and with head-of-bed elevation to 60°, for 5 minutes in each position. Data were analyzed using Kubios HRV software. The following parameters were assessed: mean RR interval, mean HR, RMSSD, SDNN, LF/HF ratio, and the non-linear index DFA $\alpha 1$. Participants were stratified according to the level of injury (above and below T5). Statistical analysis was performed using IBM SPSS Statistics 26, applying the Wilcoxon and Mann-Whitney U tests, with $p < 0.05$ considered statistically significant.

Results: A total of 33 individuals participated in the study, predominantly male, with a mean age of 35 ± 14 years. In the supine position (0°), patients with injuries above T5 showed significantly reduced mean RR intervals ($p = 0.025$), higher mean HR ($p = 0.026$), and lower autonomic complexity assessed by DFA $\alpha 1$ ($p = 0.041$) compared with those injured below T5. During head-of-bed elevation to 60°, these differences persisted for mean RR ($p = 0.013$) and mean HR ($p = 0.014$), and were associated with a significant change in the LF/HF ratio ($p = 0.030$) and a more pronounced reduction in DFA $\alpha 1$ ($p = 0.005$), indicating lower autonomic adaptability in individuals with higher-level injuries. **Conclusion:** Patients with spinal cord injury above T5 exhibit greater cardiac autonomic dysfunction and reduced adaptive capacity in response to postural changes during hospital hospitalization.

Keywords: Heart rate determination, Spinal cord injuries, Autonomic nervous system diseases, Cardiovascular physiological phenomena, Spinal cord.

INTRODUCTION

Spinal cord injury (SCI) is a neurological condition that frequently results in motor, sensory, and autonomic deficits, with cardiovascular dysfunction being one of its most complex complications, particularly in cervical and high thoracic injuries. This dysfunction occurs due to disruption of the sympathetic bulbospinal pathways that modulate cardiovascular activity, resulting in changes in blood pressure, orthostatic hypotension, and autonomic dysreflexia.^{1,2} Patients with SCI are at increased risk of arrhythmias, cardiovascular events, and hemodynamic changes during hospitalization, which directly influences prognosis.^{1,3}

Heart rate variability (HRV) is a noninvasive marker widely used to assess autonomic balance between the sympathetic and parasympathetic systems.^{4,5} HRV makes it possible to monitor the integrity of autonomic control and the capacity for cardiovascular adaptation to stressors, being especially relevant in patients with SCI.⁶ Recent studies demonstrate that HRV analysis can provide information on baseline and dynamic autonomic function, making it useful for clinical monitoring during hospitalization.⁶

Different HRV indices provide complementary information on autonomic modulation. Mean RR represents the mean of the intervals between consecutive heartbeats, reflecting baseline heart rate, whereas mean heart rate (mean HR) indicates the overall cardiac rhythm and serves as a reference for other variability metrics.^{5,7} RMSSD (root mean square of successive differences) is a sensitive indicator of parasympathetic activity and vagal tone, whereas SDNN (standard deviation of NN intervals) reflects total autonomic variability and provides an overview of sympathetic-parasympathetic balance.^{5,8}

Patients with SCI, particularly those with injuries above T5, generally show significant reductions in RMSSD and SDNN indices, indicating lower parasympathetic modulation and greater baseline sympathetic dominance.^{7,9} Studies demonstrate that these autonomic deficits become more evident during stressful situations, such as postural changes, mobilization, or medical procedures performed during hospitalization.^{3,10}

In addition, nonlinear HRV measures, such as DFA $\alpha 1$ (detrended fluctuation analysis alpha-1), provide additional information on the complexity and adaptability of heart rhythm and are important for assessing cardiovascular responsiveness to physiological changes.^{4,5} Recent evidence suggests that individuals with SCI have lower complexity of RR oscillations, reflecting deeper autonomic impairment, which reinforces the need for continuous HRV monitoring to prevent cardiovascular events.⁵

Thus, HRV assessment using indices such as mean RR, mean HR, RMSSD, SDNN, LF/HF (low-frequency to high-frequency ratio), and DFA $\alpha 1$ offers a comprehensive approach to understanding autonomic function in patients with SCI, providing important clinical information on cardiovascular risk, the ability to adapt to hospital-related stress, and the need for individualized care strategies.^{6,9}

Therefore, the present study aimed to analyze heart rate variability in patients with spinal cord injury hospitalized at Hospital de Urgências de Goiás.

METHODOLOGY

This is a cross-sectional observational study conducted in the inpatient wards of Hospital de Urgências de Goiás. The sample consisted of adult patients diagnosed with spinal cord injury who were hospitalized in the wards over a six-month period. The sample size calculation, considering an estimated population of 36 patients, resulted in the inclusion of 33 participants, ensuring a 95% confidence level and a 5% margin of error.

Individuals older than 18 years, of both sexes, with spinal cord injury and who agreed to participate by signing the Informed Consent Form were included. Patients with clinical instability,

sepsis (Sepsis-3 definition), admission to an intensive care unit, agitation or poor cooperation, previous cardiovascular disease, arrhythmias, diabetes, uncontrolled hypertension, or use of medications that could interfere with cardiac autonomic modulation were excluded.

Data collection was performed in a standardized manner by a single trained evaluator, after approval by the Research Ethics Committee of the Leide das Neves Ferreira institution (CEP/LNF), in accordance with Resolution No. 466/2012 of the National Health Council, under opinion No. 7.396.541, CAAE 85988325.1.0000.5082, registered on Plataforma Brasil. Initially, potential patients were identified for subsequent medical record review. After consent was obtained, clinical and neurological assessment was performed according to the American Spinal Injury Association (ASIA) and the Abbreviated Injury Scale (AIS), followed by the recording of sociodemographic and clinical information on a structured form, as shown in Figure 1.

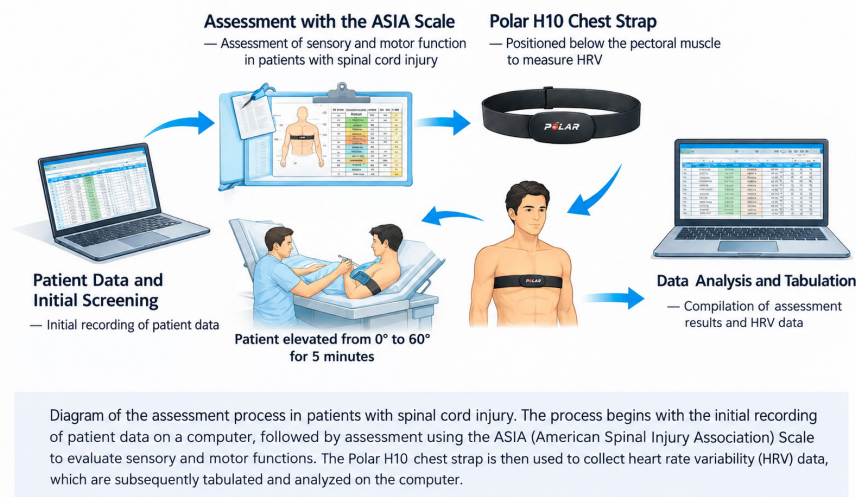


Figure 1: Procedures for Study Assessment.
Source: Prepared by the authors (2026).

For autonomic analysis, participants were positioned in the supine position for five minutes, with the head of the bed at 0°, followed by elevation to 60°. HRV was recorded using a Polar H10 chest strap positioned immediately below the pectoral muscle. Second-by-second heart rate values were exported to Microsoft Excel, converted into NN intervals by dividing HR values by 60,000, and subsequently processed using Kubios HRV software. In cases of symptoms consistent with autonomic dysreflexia or presyncope, the procedure was immediately discontinued, with the patient returned to the horizontal position.

Linear HRV indices were analyzed in the time domain (RMSSD, SDNN, pNN50) and frequency domain (HF, LF, and LF/HF ratio), in addition to the nonlinear index DFA $\alpha 1$. RMSSD was considered a marker of vagal modulation, whereas SDNN reflected overall RR interval variability; the HF (high-frequency) band was interpreted as an indicator of parasympathetic activity, while LF (low-frequency) was considered to be influenced by sympathetic and vagal mechanisms. The LF/HF ratio was interpreted as a complementary measure, considering its limitations discussed in the literature.

Data were entered into Excel spreadsheets and analyzed using IBM SPSS Statistics 26 software.

Variable normality was assessed using the Shapiro–Wilk test, and, given the non-normal distribution, nonparametric tests were used. Within-group comparisons (0° and 60° positions) were performed using the Wilcoxon test, and between-group comparisons (injury above and below T5) using the Mann–Whitney U test. The significance level adopted was $p < 0.05$.

All procedures followed the ethical principles of CNS Resolution No. 466/2012, ensuring confidentiality, anonymity, and data security. Physical and digital documents will be stored for five years and subsequently destroyed.

RESULTS

Initially, 80 patients were identified, of whom 47 were excluded, resulting in a total of 33 participants included in the analysis, as shown in Figure 2. Most participants were male, with a mean age of 35 ± 14 years. The remaining sample characteristics are presented in Table 1.

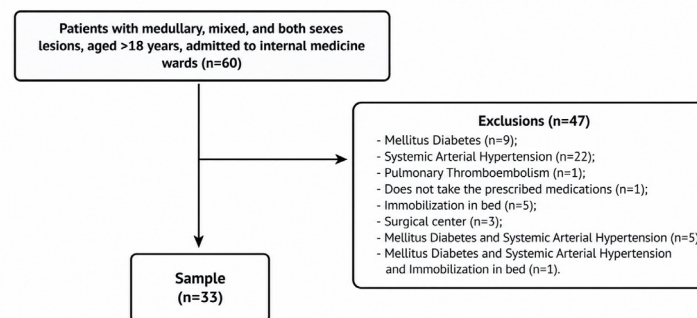


Figure 2: Sample Selection.

Source: Prepared by the authors (2026).

Table 1: Sociodemographic Characteristics.

Variable	n (%)
Sex	
Male	26 (78,8)
Female	7 (21,2)
Neurological level of injury	
Below T5	15 (45,5)
Above T5	18 (54,5)
AIS grade	
Complete (AIS A)	9 (27,3)
Incomplete (AIS B-E)	24 (72,7)
History of cardiac disease	
Yes	19 (57,6)
No	14 (42,4)
Intubation	
Yes	6 (18,2)
No	27 (81,8)
Current or previous smoker	
Yes	12 (36,4)
No	21 (63,6)
Alcoholic	
Yes	7 (21,2)
No	16 (48,5)
Socially	10 (30,3)
Underwent surgery (AVP)?	
Yes	16 (48,5)
No	17 (51,5)

Source: Prepared by Authors (2026).

The findings presented in Table 2 showed that patients with injuries above T5 had lower RR interval values and a higher mean heart rate during 60° tilt compared with the resting condition. A decrease in RMSSD values, a marker directly related to parasympathetic modulation, was also observed. Taken together, these findings suggest poorer autonomic adaptation to the stress of orthostatic positioning, characterized by a reduced ability of the parasympathetic nervous system to modulate the cardiovascular response to postural change.

Table 2: Within-Group Comparisons – Injury Above T5.

Variable	Z	0°	60°	p
RR Médio	-2,069	906 626 – 953	863 648 – 920	0,039
Mean HR	-2.142	66 63 – 95	69 65 – 92	0.032
RMSSD	-2.038	6.5 4.1 – 7	5.3 4.2 – 6.5	0.042
SDNN	-0.568	8.2 5 – 11.9	8.4 5.2 – 11.3	0.570
pNN50	-1.000	0	0	0.317
LF/HF	-0.588	3.3 2.0 – 5.6	3.9 2.3 – 8.5	0.557
LF	-0.118	27 8 – 109.2	22 10 – 105	0.906
HF	-1.781	8.5 4.7 – 14	6 3.7 – 10.7	0.075
DFA $\alpha 1$	-0.283	1.2 1.1 – 1.5	1.2 1.0 – 1.5	0.777

Variables are expressed as median and interquartile range. Mean HR (heart rate); RMSSD (root mean square of successive differences); SDNN (standard deviation of NN intervals); pNN50 (percentage of adjacent NN intervals that differ by more than 50 ms); LF/HF (low-frequency to high-frequency ratio); LF (low frequency); HF (high frequency); DFA $\alpha 1$ (detrended fluctuation analysis alpha-1).

Source: Prepared by Authors (2026).

Among patients with spinal cord injury below T5, as shown in Table 3, the Wilcoxon test indicated significant differences between the evaluated time points for some variables.

Table 3: Within-Group Comparisons – Injury Below T5.

Variable	Z	0°	60°	p
Mean RR	-2.159	675 572 - 779	615 566 - 796	0.031
Mean HR	-2.171	89 77 - 105	98 75 - 106	0.030
SDNN	-2.073	9.8 7.1 – 13.3	13.2 7.8 – 14.6	0.038
RMSSD	-0.853	5 4 – 6.1	5.2 4 – 6.1	0.394
pNN50	-1.000	0	0	0.317
LF/HF	-1.079	6.1 2.5 – 14.4	11.6 5.2 - 30	0.281
LF	-1.363	53 18 - 123	78 21 - 266	0.173
HF	-0,144	8 5 - 11	7 4 - 10	0.886
DFA $\alpha 1$	-1,590	1.5 1.4 – 1.7	1,6 1.4 – 1.8	0.112

Variables are expressed as median and interquartile range. Mean HR (heart rate); SDNN (standard deviation of NN intervals); RMSSD (root mean square of successive differences); pNN50 (percentage of adjacent NN intervals that differ by more than 50 ms); LF/HF (low-frequency to high-frequency ratio); LF (low frequency); HF (high frequency); DEA $\alpha 1$ (detrended fluctuation analysis alpha-1).

Source: Prepared by Authors (2026).

The comparison between patients with injuries above T5 and those with injuries below T5 revealed significant differences as early as the 0° position (supine), as shown in Table 4. The group with injuries above T5 showed relevant variations in mean RR interval ($p = 0.025$) and mean heart rate ($p = 0.026$), indicating that these individuals have a distinct baseline cardiac pattern, possibly resulting from reduced sympathetic autonomic modulation originating in the upper thoracic segments. In addition, the DFA $\alpha 1$ index also differed between the groups ($p = 0.041$), suggesting lower complexity and adaptability of beat-to-beat fluctuations in this group, reflecting less efficient autonomic regulation.

Table 4: Between-Group Comparisons – Injuries Above and Below T5.

Variable	0° Acima T5	0° Abaixo T5	p (0°)	60° Acima T5	60° Abaixo T5	p (60°)
Mean RR	906 (626 - 953)	675 (572 - 779)	0.025	863 (671 - 907)	615 (578 - 781)	0.013
Mean HR	66 (63 - 95)	89 (77 - 105)	0.026	69 (66 - 89)	98 (76 - 104)	0.014
DFA α	1.29 (1.10 - 1.55)	1.50 (1.46 - 1.75)	0.041	1.29 (1.07 - 1.5)	1.66 (1.4 - 1.81)	0.005
LF/HF	3.37 (2.04 - 5.67)	6.10 (2.56 - 15.4)	0.112	3.98 (2.40 - 8.22)	11.6 (5.3 - 23.51)	0.030

Variables are expressed as median and interquartile range. Mean HR (heart rate); DFA $\alpha 1$ (detrended fluctuation analysis alpha-1); LF/HF (low-frequency to high-frequency ratio).

Source: Prepared by Authors (2026).

At the 60° position, the differences between patients with injuries above T5 and those with injuries below T5 remained evident. A significant difference was observed in mean RR interval ($p = 0.013$) and mean heart rate ($p = 0.014$), indicating that, even under orthostatic stress, the groups maintained distinct patterns. These differences suggest that individuals with injuries above T5 have a reduced capacity for cardiovascular adjustment in response to postural change.

In addition, the LF/HF ratio also differed between the groups ($p = 0.030$), demonstrating that the sympathetic-parasympathetic balance in response to tilting is significantly altered in patients with injuries above T5, reflecting a possible inability to adequately activate the sympathetic.

DISCUSSION

Based on the results of this study, differences in cardiac autonomic modulation were observed between patients with spinal cord injury (SCI) above and below T5, both in the 0° supine position and during 60° tilt. These differences are consistent with the established pathophysiology of high-level SCI, characterized by disruption of the sympathetic bulbospinal pathways responsible for thoracic innervation, leading to reduced peripheral vasoconstriction, impaired autonomic adjustment to postural stress, and greater cardiovascular vulnerability.^{1,11} Recent studies reinforce that cervical and high thoracic injuries are associated with a greater risk of resting tachycardia, orthostatic hypotension, and significant autonomic instability.^{1,11}

Individuals with SCI above T5 exhibited reduced mean RR and increased mean HR at both 0° and 60°, indicating sustained tachycardia. This is consistent with studies that evaluated autonomic

and hemodynamic responses in high-level SCI, showing a higher resting HR and lower variability attributed to the loss of supraspinal sympathetic modulation.^{1,12,13}

The reduction in RMSSD in the group with injuries above T5 found in this study indicates lower vagal modulation, a finding already described in the literature. Accordingly, studies evaluating time-domain indices have shown reductions in RMSSD and SDNN in individuals with SCI, especially at higher injury levels, reflecting loss of autonomic variability and a reduced capacity for rapid response to changes such as postural shifts.^{7,10,13} These parameters have been associated with an increased risk of hemodynamic events during head-of-bed elevation and with symptoms of orthostatic hypotension.^{7,13}

Regarding the analysis of nonlinear metrics, specifically DFA α_1 , the reduced values in patients with SCI above T5 reflect lower adaptability.¹⁴ DFA α_1 captures aspects of autonomic regulation that are not detectable by linear indices and is sensitive to reductions in the adaptive capacity of the nervous system.¹⁴

Furthermore, the change in the LF/HF ratio during head-of-bed elevation in patients with SCI above T5, despite the limitations of this ratio as an isolated measure of sympathovagal balance, is supported by studies showing that this ratio changes consistently during orthostatic stimuli, representing difficulty in producing an adequate autonomic response to the generated stress^{6,9}. In any case, the change observed in the LF/HF ratio is consistent with the expected response during tilting described in individuals with high-level SCI.^{6,9}

These differences between the groups, both in the 0° supine position and during tilt, reinforce that orthostatic stress exacerbates a pre-existing autonomic dysfunction. Patients with SCI above T5 have a reduced capacity for sympathetic recruitment and lower dynamic variability, making them more vulnerable to decreases in blood pressure and inadequate cardiac responses during mobilization.^{1,10,13}

Studies show that the integrated interpretation of HRV, combining time-domain indices (mean RR, mean HR, RMSSD, SDNN), frequency-domain indices (LF/HF), and nonlinear metrics (DFA α_1), provides a more comprehensive analysis of autonomic dysfunction after SCI. Thus, its relevance supports HRV as a noninvasive tool for identifying patients at greater risk of cardiovascular instability, guiding mobilization, supporting management strategies, volume management, pharmacotherapy, and continuous monitoring.^{10,15}

This study has some limitations that should be considered when interpreting the results. Initially, during the pilot study, it was observed that not all hospital beds allowed exactly the same positioning angle to be achieved, which may have resulted in small variations in body inclination among participants, with a potential influence on the physiological responses evaluated. Finally, technical difficulties related to the processing of heart rate variability data required conversion of the signals into a format compatible with Kubios software, which may represent an additional limitation related to data processing.

CONCLUSION

It is concluded that the findings of this study support the proposed hypothesis, demonstrating that the level of spinal cord injury exerts a significant influence on cardiac autonomic control. Individuals with spinal cord injury above T5 showed more pronounced autonomic impairment than those with injuries below this level, evidenced by lower mean RR, higher baseline heart rate, reduced RMSSD, and lower complexity of the RR series (DFA α_1), both at 0° and during 60° tilt. The presence of differences between the groups in the supine position and their persistence during head-of-bed elevation reinforce that autonomic dysfunction in high-level injuries is persistent and worsens with postural changes.

Finally, these findings reinforce that HRV analysis is a useful tool for identifying relevant

autonomic limitations and guiding monitoring strategies and safe mobilization in individuals with high-level spinal cord injury.

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MAILING ADDRESS

GIULLIANO GARDENGHI

Rua Gurupi, S/N - Quadra 25 - Lote 06/08 - Vila Brasília, Aparecida de Goiânia, Goiânia/GO, Brasil.

E-mail: coordenacao.cientifica@ceafi.edu.br

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Authors:

Nathália Moura Gonçalves - <http://lattes.cnpq.br/3704788436791333> - <https://orcid.org/0009-0007-0602-5777>

Giulliano Gardenghi - <http://lattes.cnpq.br/1292197954351954> - <https://orcid.org/0000-0002-8763-561X>

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Library Review: Izabella Goulart

Spell Check: Dario Alvares

Translation: Soledad Montalbetti

Received: 23/09/26. Accepted: 01/09/26. Published in: 02/10/2026.