REVIEW

Influence of the neurological level of spinal cord injury on cardiovascular outcomes in humans: a meta-analysis

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Background: Although motor and sensory deficits following spinal cord injury (SCI) are well known, there are still contrasting reports on how SCI affects baseline cardiovascular (CV) parameters and other autonomic functions.

Study design: Meta-analysis is performed.

Objectives: To examine the effect of injury level on supine and seated CV function in individuals with SCI.

Methods: A total of 98 studies representing 1968 individuals were retrieved for analysis. Systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate (HR) were abstracted from the studies and compared between four groups according to the neurological lesion level, cervical (C) SCI (C4–C8), high-thoracic (HT) SCI (T1–T6), low-thoracic lumbar (LTL) SCI (below T6) and able-bodied (AB) controls.

Results: In the supine position, SBP, DBP and HR were lower in C compared with HT, LTL and AB (all $P < 0.04$). In the seated position, SBP and DBP were significantly lower in C compared with LTL and AB (all $P < 0.003$) and HR was significantly lower in C compared with LTL only ($P = 0.01$). A final finding was that C exhibited a lower resting SBP in the seated compared with the supine position ($P < 0.001$).

Conclusion: Individuals with SCI exhibit a lesion-dependent impairment in resting CV function, whereby those with the highest injury had the greatest degree of CV dysfunction. A further finding was that individuals with a C injury exhibited a lower resting SBP in the seated vs supine position. Thus, clinicians and researchers should consider lesion level and body position when measuring and interpreting CV parameters in individuals with SCI.

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Keywords: autonomic; paraplegia; tetraplegia; blood pressure; heart rate

INTRODUCTION

A spinal cord injury (SCI) is a devastating condition that leads to a variety of motor, sensory and autonomic dysfunctions that have a negative effect on quality of life. Recently, there has been a growing clinical and basic science interest in the consequences of injury to the autonomic nervous system, and the subsequent impact on cardiovascular (CV) functions.^{1–3} The autonomic nervous system is involved in the control of various body functions including the modulation of peripheral vasomotor tone, coronary blood flow, heart contractility, heart rate (HR) and blood pressure (BP). Following SCI, a lesion-dependent impairment in autonomic functions⁴ combined with physical deconditioning and a limited ability to participate in exercise conspire to create abnormal CV control compared with healthy able-bodied (AB) individuals.⁵ The presence of impaired CV control among individuals with SCI and the latest data indicating CV dysfunctions are responsible for the greatest proportion of morbidity and mortality in this population,⁶ highlight the need for an evaluation of CV control in these individuals.

In the SCI population where the ‘intervention’ level and completeness of SCI, cannot be ethically randomized, one must rely on observational studies to make inferences about how SCI affects CV function. Unfortunately, the majority of such observational studies in

SCI are limited by a small number of participants. Small sample sizes can be partially mitigated with the use of meta-analytical methods. Meta-analysis is a well-known statistical tool in evidence-based medicine that can be used to combine the results of studies in an attempt to overcome the problem of reduced statistical power due to small sample sizes, and thus allow for more accurate data analysis.⁷ Increased statistical power gives more confidence in applying study results to clinical practice as well as research. Although meta-analyses of randomized control trials are preferred over that of observational studies, the number of published meta-analyses of observational trials have increased over the years⁸ and guidelines currently exist for reporting the results of observational study-based meta-analyses.⁹

Accordingly, we propose to use an established meta-analytical method for synthesizing observational studies in order to examine the effect of neurological level of injury on various CV outcomes (BP and HR) at rest in individuals with SCI. Potential confounding factors that are thought to affect CV responses, including age,^{10,11} sex,¹² duration of SCI^{13–16} and level of fitness,¹⁷ are also considered to obtain adjusted results. We hypothesize that there will be a lesion-dependent impairment in CV function, whereby systolic BP (SBP), diastolic BP (DBP) and HR will be lower in those with the highest (cervical (C)) injuries.

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METHODS

Search strategy

A literature search was conducted through the Cochrane database of Systematic Reviews and Medline (OVID) using the search filter developed by the Scottish Intercollegiate Guidelines Network (2007). Further, electronic searches were conducted to identify relevant studies published between January 1980 and December 2007 using the following databases: Medline, Embase, CINAHL and Sport Discus. The search strategies included all the relevant terms including 'SCI', 'autonomic nervous system', 'HR' and 'BP' ('SBP', 'DBP' and 'mean').

Study eligibility criteria

Studies were included in the review if they were randomized control trials, controlled clinical trials (includes quasi-randomized, cross-over and before-after design), prospective cohorts, case-control and cross-sectional studies reporting CV outcomes at rest (HR and/or BP sitting or supine) in individuals with SCI. Only articles written in English were reviewed because of limited funding. Studies were excluded if they were case-reports, case-series, narrative reviews, retrospective cohorts or written in a non-English language. For studies that examined multiple groups, any group that had <4 subjects was excluded and any group with >4 subjects was included. When absolute values of BP and HR were not given and the means or s.d. could not be extrapolated from figures, authors were contacted for their results via email. If two attempts at contact separated by at least 2 weeks failed, the study was excluded based on insufficient data. If an email address could not be found either in the paper or through an internet search of all authors, the study was excluded. Studies that did not separate their cohort by lesion level were excluded.

Participant selection criteria

Adults aged ≥ 16 years with chronic (>6 weeks) SCI who were in a stable medical condition were included, as were control groups of AB individuals. Participants were excluded if they had a congenital SCI, lower motor neuron injury, if they were assessed for CV outcomes when medically unstable, or on medications known to affect the sympathetic nervous system or CV function. Studies using invasive monitoring devices whose nociceptive stimuli can elicit a change in CV parameters were also excluded.

Groups for outcome analysis

Neurological level of SCI. Many studies used various terms to classify their subjects; quadriplegic vs C, paraplegic vs thoracolumbar. For consistency in this manuscript, we present data for the following neurological levels of SCI: C (C4-C8), high-thoracic (HT: T1-T6), low-thoracic lumbar (LTL: T7-L5) and AB.

Completeness of SCI. Currently the most widely used method of determining completeness and neurological level of SCI is the International Standards for the Neurological Classification of SCI that utilizes the American Spinal Injury Association Impairment Scale (AIS).¹⁸ This divides individuals into sensory and motor complete (AIS A), motor complete (AIS B), and motor and sensory incomplete (AIS C and D). When available, participants were divided into motor complete (AIS A and B) or incomplete (AIS C and D). When earlier studies were included into the analyses, before the introduction of AIS assessment, the Frankel classification was used to determine motor complete (A and B) and incomplete (C and D) injuries.

Potential confounders. Age and physical conditioning were considered as potential confounders. Age was recorded as continuous data.

Physical conditioning was considered as either conditioned or deconditioned. Conditioned subjects must either have been documented as being physically active or have participated in a regular training program with the purpose of increasing fitness level.

CV outcome measures

The primary dependent variables were HR, SBP and DBP. Baseline responses were subdivided into supine and seated responses as differences in CV parameters between the two positions have been demonstrated in individuals with C SCI.¹⁹

Selection of studies and data extraction. Two primary reviewers (PM and AK) independently reviewed the abstracts. If abstracts were not available, the same two reviewers reviewed the title and/or portions of text. Disagreement was resolved through consensus to discuss and, if necessary, by third party resolution. Those papers meeting the inclusion criteria were reviewed in full by the same two independent reviewers and data were extracted into a spreadsheet.

Assessment of methodological quality. Meta-analysis of observational studies inevitably results in a greater variation than that associated with randomized control trials or interventions. To account for this variation, different study designs were analyzed together, providing the criteria for participants, and interventions were met in order to allow comparisons across studies. In studies with multiple measurements taken on different days or at different times, only the first measurement was included in order to obtain a cross-sectional outcome regardless of the original study design.

Data analysis and synthesis

Meta-analytic estimates of population means for CV parameters (SBP, DBP and HR) were calculated in each position (supine and sitting) via the random effects model of DerSimonian and Laird.²⁰ Sample means and 95% confidence intervals were computed for each neurological injury level (C, HT and LTL) and for AB. All four groups were compared via the Q-test for heterogeneity. Pairwise comparisons between groups were conducted via linear contrasts applied to the random effects model. For each outcome and position, all studies that reported mean and variance estimates were included. Publication bias was tested using Kendall's tau rank correlation test for funnel plot asymmetry.²¹ Forest plots were derived to display effect estimates with 95% confidence intervals for individual trials and pooled results (Figure 1). Relationships between age and time since SCI and supine SBP were assessed for those studies, in which an average age and time since SCI were reported. The relationship between these covariates and supine SBP was assessed with a weighted regression, in which the weights for each study were defined as the inverse of the sum of the between-study variance from a meta-analysis of the available studies and the estimated variance of each study. Analyses were conducted using the open-source R software package (R Foundation for Statistical Computing, Vienna, Austria) with the metafor add-on package.²² All the hypothesis tests were conducted at the 0.05 level.

Sensitivity analysis. Galbraith plots were constructed to spot outliers. Data were reanalyzed with and without outliers. Serious outliers were further assessed with respect to quality and confounders were identified.

RESULTS

Description of studies

Primary and secondary electronic search based on identified criteria revealed a total of 271 studies of interest for the meta-analysis.

Figure 1 Example of meta-analytical comparison of resting supine DBP between individuals with cervical SCI (left-panel) and low-thoracic lumbar SCI (right-panel).

Of these studies, 98 studies met inclusion criteria and yielded data on 1968 individuals. Descriptive characteristics of the included studies are reported in Table 1. The majority of studies included individuals with various levels of SCI, of which C (66%) and/or LTL (40%) injuries composed the majority. An AB control group was included in 57% of studies, whereas only 10% of studies reported data on HT individuals. Sex was reported in 78% of studies, of which men accounted for 91% of study participants. No study specifically investigated CV function in women, rather, 31% of studies included a small number of women but did not split their analyses by sex. Completeness of injury was reported in 62% of studies, of which 91% of studies focused on individuals with complete injuries. Only three studies included individuals with incomplete injuries but did not split their analyses by completeness of injury.

Exclusions

Reasons for exclusion of 173 studies included: missing data on absolute values for BP and HR, absence of s.d., grouping of lesion levels, duplication of data in publications, variability in protocol for CV evaluations, small number of subjects in the study (<4 subjects), inclusion of non-traumatic SCI individuals (spina bifida, polio and amputees) and presence of medication affecting CV outcomes.

Potential confounders

There were no significant between-group differences for age or time post injury across lesion levels ($P < 0.05$). We were unable to test for differences in complete vs incomplete and conditioned vs non-conditioned because only three studies reported data on incomplete injuries and only two studies reported data on conditioned individuals across all lesion levels. Kendall's tau for funnel plot asymmetry was significant for seated HR only ($P = 0.03$).

CV parameters

Table 2 presents meta-analytically obtained CV parameters by level of injury in the supine and seated position.

Supine CV parameters

We found that SBP significantly differed between all the four groups, whereby SBP was lower in C compared with HT ($P = 0.03$), LTL ($P = 0.0001$) and AB ($P < 0.0001$; see Figure 2). We also found that DBP was lower in C compared with HT ($P = 0.01$), LTL ($P = 0.02$) and AB ($P = 0.001$), and HR was lower in C compared with HT ($P = 0.03$), LTL ($P = 0.008$) and AB ($P = 0.002$). There were no differences in any CV outcome between the HT, LTL and AB groups.

Sitting CV parameters

Only two studies investigated seated CV parameters in HT; hence *post-hoc* pairwise comparisons for HT were not considered. Similar to the supine position, we found that SBP and DBP were significantly lower in C compared with LTL and AB (all $P < 0.003$; see Figure 3). However, HR was only different between C and LTL ($P = 0.01$). A cross-comparison of CV variables between the seated and supine position for all levels of injury revealed that the seated position was associated with a lower SBP only in C ($P < 0.0001$). No other differences between seated and supine values for any dependent variable or group were present.

Effect of age and time post injury

The weighted regression coefficients for supine CV parameters by lesion level against time since injury and age are presented in Table 3. There were significant positive associations between age and SBP in HT and AB, and age and DBP in HT only. Also, time since injury was

Table 1 Descriptive characteristics of papers reviewed (n=98)

Characteristic	No. of studies	Reference
<i>Level of SCI</i>		
C	65	3, 40, 42–104
HT	10	50, 66, 71, 72, 79, 88, 90, 91, 105, 106
LTL	40	40, 41, 44, 64, 68, 71–73, 77, 81, 82, 88, 91, 97, 99, 103, 104, 106–128
AB	56	3, 5, 43, 46, 50, 53, 55, 64–66, 68, 70, 73–79, 81, 84, 87, 88, 92, 93, 97–100, 102–105, 107, 111–115, 117–121, 123–126, 129–136
<i>SCI sample size</i>		
<10	43	41, 42, 47, 55–58, 62, 67, 70, 74–76, 78, 80, 84–87, 89, 92, 93, 96, 98, 100–102, 108, 111, 113, 116, 119, 121–125, 127, 130, 131, 133–135
10–20	33	43–46, 48, 49, 51, 53, 54, 59, 61, 63, 65, 69, 73, 77, 79, 81, 90, 94, 99, 105–107, 109, 112, 114, 115, 120, 126, 128, 129, 132
20–50	20	3, 40, 50, 52, 60, 64, 66, 68, 71, 72, 82, 83, 88, 95, 97, 104, 110, 117, 118, 137
> 50	2	91, 103
<i>Sex</i>		
Male	48	41–44, 46, 49, 53, 54, 58, 59, 62, 64, 68, 71, 74, 75, 78, 80, 84, 87–93, 97, 99–102, 106, 108, 110, 111, 114, 115, 117, 121, 123–129, 131, 132
Female	0	
Both	30	3, 45, 50–52, 55–57, 61, 63, 65–67, 70, 73, 79, 83, 85, 86, 94, 95, 103–105, 112, 113, 118, 120, 122, 134
Not specified	20	40, 47, 48, 60, 69, 72, 76, 77, 81, 82, 96, 98, 107, 109, 116, 119, 130, 133, 135, 137
<i>SCI severity</i>		
Complete	58	40, 41, 44, 48, 50–55, 58, 61, 62, 65, 66, 68, 70, 72–79, 81–87, 92–95, 102–104, 106, 107, 113–115, 117–121, 123, 124, 126, 128, 130, 131, 133, 134, 137
Incomplete	0	
Both	3	49, 59, 64
Not specified	37	3, 42, 43, 45–47, 56, 57, 60, 63, 67, 69, 71, 80, 88–91, 96–101, 105, 108–112, 116, 122, 125, 127, 129, 132, 135

Abbreviations: AB, able-bodied; C, cervical; HT, high-thoracic; LTL, low-thoracic lumbar; SCI, spinal cord injury.

positively associated with DBP in LTL. No other significant associations were found between any CV parameters and age or time since injury.

DISCUSSION

The objective of this meta-analysis was to examine the relationship between the neurological level and severity of SCI and CV outcomes. In line with our original hypothesis, we found a lesion-dependent impairment in resting CV function, whereby those with the highest injury had the greatest degree of CV dysfunction. A further finding was that individuals with a C injury exhibited a lower resting BP in the seated vs supine position.

Effect of lesion level on supine CV parameters

The effect of lesion level on BP parameters was in keeping with our hypothesis; that is, the higher the neurological level of injury, the greater the degree of CV dysfunction. It was surprising, however, that we did not find differences in resting SBP between HT and LTL or HT and AB in the supine position. We had anticipated that individuals with HT would also exhibit a significantly lower SBP than LTL and AB, due to loss of tonic sympathetic control of the splanchnic bed. That we found a similar SBP between HT, LTL and AB suggests either that sympathetic control of the splanchnic bed does not have such a critical role in BP regulation as had been previously thought^{1,15}, or that a relatively small number of studies with a large between-study variance in the HT group precluded a significant difference from being detected. We believe it is the latter of these that explains why HT did not exhibit a statistically significant lower BP than either LTL or AB. Indeed, Figures 2 and 3 demonstrate that although the mean value for SBP was lower in HT than LTL and AB in both the seated and supine position, there was a much larger variance in results for the HT group. A larger variability of CV parameters in HT may be explained by variability in sympathetic preservation of neural control of the heart and upper body vasculature. For example, individuals with a T1 lesion will be devoid of supraspinal sympathetic control, individuals with a T1–T5 lesion will have partial preservation of sympathetic function and individuals with an injury below T5 will have full supraspinal sympathetic control of the heart and upper body vasculature. This most likely also explains why such few studies have investigated the HT population.

Effect of body position on CV parameters

In general, individuals with C SCI exhibited a 15 mm Hg lower resting SBP in the seated compared with supine position. This finding is in keeping with the high prevalence of orthostatic hypotension that is commonly reported in individuals with high-level SCI.^{19,23} In individuals with a LTL SCI or in the AB population, BP is maintained in the seated position due to a baro-receptor induced sympathetically mediated vasoconstriction. Thus, a lower BP in the seated position in individuals with C SCI is likely a consequence of disruption to the spinal sympathetic pathways, which would be expected to affect the peripheral vascular resistance response to an orthostatic challenge in the seated position.¹⁹ The recognition of how arterial BP changes depending on body position in the C SCI population is of extreme clinical importance. Low BP in the seated position could result in symptoms that are characteristic of orthostatic hypotension.¹⁹ Orthostatic hypotension is commonly associated with increased fatigue, a decline in cognitive functions, and often requires pharmacological management.^{24,25} A perhaps less intuitive but equally important consequence of low-seated BP is that it may prevent individuals from participating in rehabilitation or activities of daily living.^{23,26} Thus, BP should always be measured both in the supine and seated position before deciding on an appropriate intervention for individuals with C and HT SCI.

LIMITATIONS

Effect of motor and sensory completeness of SCI on CV parameters

Most of the studies that met the inclusion criteria for this meta-analysis either failed to document severity of SCI or grouped subjects with complete and incomplete (motor and sensory) injuries for analysis. Thus, we were unable to determine the impact of completeness of SCI on CV outcomes. Determining whether an injury is complete or incomplete, which indicates whether all motor, sensory and autonomic pathways are disrupted or spared, respectively, is

Table 2 Comparison between supine and seated cardiovascular variables by lesion level

SBP (mm Hg) (CI)		DBP (mm Hg) (CI)		HR (b.p.m.) (CI)	
Supine	Sitting	Supine	Sitting	Supine	Sitting
C					
110 (107, 113)	96* (92, 99)	66 (63, 68)	64 (61, 67)	64 (62, 67)	68 (65, 71)
31 Studies, <i>n</i> =345	11 Studies, <i>n</i> =124	27 Studies, <i>n</i> =284	11 Studies, <i>n</i> =124	31 Studies, <i>n</i> =336	18 Studies, <i>n</i> =192
HT					
120† (114, 127)	100 (87, 112)	74† (68, 80)	64 (54, 74)	71† (65, 78)	73 (63, 83)
6 Studies, <i>n</i> =86	2 Studies, <i>n</i> =16	6 Studies, <i>n</i> =86	2 Studies, <i>n</i> =16	5 Studies, <i>n</i> =81	2 Studies, <i>n</i> =21
LTL					
122† (119, 126)	124† (121, 128)	71† (68, 75)	77† (74, 81)	72† (69, 76)	76† (73, 78)
18 Studies, <i>n</i> =207	12 Studies, <i>n</i> =133	15 Studies, <i>n</i> =158	12 Studies, <i>n</i> =129	11 Studies, <i>n</i> =131	18 Studies, <i>n</i> =195
AB					
121† (118, 124)	124† (120, 127)	72† (69, 75)	77† (73, 81)	69† (66, 71)	69 (66, 73)
25 Studies, <i>n</i> =311	9 Studies, <i>n</i> =127	21 Studies, <i>n</i> =246	8 Studies, <i>n</i> =119	27 Studies, <i>n</i> =294	15 Studies, <i>n</i> =181

Abbreviations: AB, able-bodied; C, cervical; CI, confidence interval; DBP, diastolic blood pressure; HR, heart rate; HT, high-thoracic; LTL, lumbar low-thoracic; *n*, number of participants; SBP, systolic blood pressure.

Data are presented as group mean and 95% confidence interval of the meta-analysed studies.

*Significantly different vs supine in that group ($P<0.05$).

†Significantly different vs cervical in the same position ($P<0.05$).

challenging for both clinicians and researchers alike. Currently, the most popular clinical and research method of describing completeness of SCI is the AIS Impairment Scale.^{18,27} The advantage of this method is that it is a bedside examination that is economical, fairly easy and fast to administer, and minimally invasive. The disadvantage is that this classification does not consider the autonomic pathways.²⁸ In recognition of the limitations of the current AIS in the clinical setting, recent recommendations have been provided for standardized documentation of autonomic functions following SCI.² However, this has yet to be consistently applied in the clinical and research setting. Consequently, a number of studies have now documented that individuals classed as AIS A or B exhibit evidence of preserved spinal autonomic pathways,^{3,29,30} as determined by the sympathetic skin response test, which is an established test for sudomotor autonomic nervous system function.^{31–34} Those studies support the concern that the sole use of the AIS scale for assessing completeness of SCI may result in individuals who have autonomically complete and incomplete injuries being analyzed together, which would be a major confounder when the outcomes of interest include CV or other autonomic parameters. Thus, future studies that aim to examine the effect of completeness of injury on CV parameters should consider the inclusion of a more robust measure of autonomic function.

Effect of age and duration of injury on supine CV parameters

We used meta-regression to explore potential differences in CV outcomes when considering age and duration of SCI. We confirm previous research in the AB population by demonstrating a significant increase in SBP with advancing age in the AB group.³⁵ For SCI, however, only HT exhibited a significant positive relationship between age and SBP. It must be borne in mind, however, that the HT regression was conducted on just six studies; thus, the results should be interpreted with caution and await verification in a larger group of individuals with HT SCI. No positive relationships were found between age and SBP or DBP in either C or LTL, which suggests the debilitating consequences of SCI supersede the normal age-dependent increase in BP that is found in AB individuals. With the exception of

the LTL group, we also found no significant relationships between duration of SCI and resting CV parameters. However, making inferences regarding causality from cross-sectional studies is inherently problematic. Thus, longitudinal studies that track BP changes from the acute-to-chronic stages of SCI and across the lifespan of individuals with SCI are needed to confirm whether CV function is altered with advancing time since injury and age. Unfortunately we were unable to examine the effect of sex on CV function. Although 78% of studies reported sex, men accounted for 91% of those studied. This ratio of males-to-females cannot be explained entirely by greater incidence of SCI in men vs women, because the ratio of those who suffer an SCI has remained at approximately four men to one woman over the last 30 years.³⁶ Regardless of the cause of this sex difference in research participants, the number of research studies investigating CV function in females with SCI is alarmingly low and warrants immediate attention.

Grouping of lesion levels

The largest obstacle encountered during the data abstraction was the lack of separation of lesion levels among individuals with SCI. Although the grouping of participants is tempting to improve statistical power in a population where low subject numbers are inherent, it should be noted that this is not appropriate when examining changes in CV function, because the autonomic nervous system is integral to determining the degree of residual CV function.¹ Indeed, when participants with C SCI are grouped with HT SCI, it has been reported that no differences in SBP exist between those with C/HT SCI and those with LTL SCI.³⁷ Thus, we recommend that investigators should divide individuals with SCI into separate groups of C, HT (above T6), LT (below T6) or lumbar injuries. Such grouping of subjects will avoid the potential confounder of grouping individuals with intact and with non-intact autonomic control of the heart and vasculature.

Publication bias

The meta-analysis of observational studies is prone to publication bias^{38,39} and results must be interpreted with caution. However, this

Figure 2 Individual study (grey symbols) and group mean (black symbol) $\pm$ 95% confidence interval for seated SBP (top), DBP (middle) and HR (bottom) in individuals with C (squares), HT (triangles), LTL (diamonds) SCI and AB (circles) controls. *Different from C, $P < 0.05$.

Figure 3 Individual study (grey symbols) and group mean (black symbol) $\pm$ 95% confidence interval for seated SBP (top), DBP (middle) and HR (bottom) in individuals with C (squares), HT (triangles), LTL (diamonds) SCI and AB (circles) controls. *Different from C, $P < 0.05$.

bias can be partially mitigated with the use of stringent study and participant inclusion/exclusion criteria, and meta-analysis of observational studies remains a useful tool to understand and quantify sources of variability in results across studies.⁹ In the current meta-analysis, we attempted to mitigate this bias by incorporating a broad set of inclusion criteria into our study design. Indeed, our test for publication bias revealed a significant effect for seated HR only and this appears to be a result of two outlying studies^{40,41} rather than apparent publication bias. That said, we only included studies written in English, providing a potential source of language bias. It was also unfortunate that one of our subgroups for analysis (HT) was much smaller than the other groups. This likely resulted in insufficient statistical power to detect differences between certain group comparisons. Thus, we believe our findings of a non-statistical difference in SBP and DBP between HT and LTL, as well as HT and AB should be interpreted with caution. Further studies are required to determine changes in SBP and DBP following HT SCI.

Table 3 Regression co-efficients for supine cardiovascular parameters by lesion level against age and time since injury

Outcome	Group	Age (years)		Time Since SCI (years)	
		Co-efficient (CI)	P-value	Co-efficient (CI)	P-value
SBP	C	0.36 (−0.39, 1.11)	0.34	−0.87 (−1.90, 0.17)	0.10
	HT	2.94 (0.58, 5.30)	0.01	1.43 (−0.75, 3.60)	0.20
	LTL	−0.18 (−1.27, 0.91)	0.74	0.36 (−1.03, 1.75)	0.61
	AB	0.40 (0.05, 0.75)	0.03		
DBP	C	0.07 (−0.36, 0.49)	0.75	−0.2 (−0.99, 0.59)	0.62
	HT	2.35 (0.9, 3.81)	<0.001	1.08 (−0.56, 2.73)	0.20
	LTL	0.35 (−0.59, 1.29)	0.46	1.32 (1.1, 1.54)	<0.001
	AB	−0.05 (−0.56, 0.47)	0.86		
HR	C	0.05 (−0.38, 0.48)	0.82	−0.26 (−0.85, 0.34)	0.40
	HT	−0.03 (−3.62, 3.55)	0.99	−1.38 (−2.89, 0.13)	0.07
	LTL	0.11 (−0.87, 1.09)	0.82	0.47 (−2.5, 3.43)	0.76
	AB	0.33 (−0.32, 0.99)	0.32		

Abbreviations: AB, able-bodied; C, cervical; CI, confidence interval; DBP, diastolic blood pressure; HR, heart rate; HT, high-thoracic; LTL, low-thoracic lumbar; SBP, systolic blood pressure.

CONCLUSIONS

We are still only at the beginning of understanding the complexity of the effects of the SCI on the autonomic nervous system and the subsequent changes to bodily systems. To date, there are conflicting reports on the severity of autonomic CV dysfunctions among individuals with SCI. Using meta-analytical techniques we demonstrate that individuals with SCI exhibit a lesion-dependent impairment in resting CV function, whereby those with the highest injury have the lowest BP and HR. We also found that individuals with C SCI exhibit a lower BP in the seated compared with supine position. Thus, clinicians and researchers alike should consider lesion level and body position when measuring and interpreting CV parameters in individuals with SCI. Future studies are required to investigate the effects of sex and autonomic completeness of injury on the CV outcomes in individuals with SCI.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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