Review

Cardiac arrhythmias associated with spinal cord injury

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Context/Objectives: To review the current literature to reveal the incidence of cardiac arrhythmias and its relation to spinal cord injury (SCI).

Methods: Data source: MEDLINE database, 304 hits, and 32 articles were found to be relevant. The relevant articles all met the inclusion criteria: (1) contained original data (2) on cardiac arrhythmias (3) in humans with (4) traumatic SCI.

Results: In the acute phase of SCI (1–14 days after injury) more cranial as well as more severe injuries seemed to increase the incidence of bradycardia. Articles not covering the first 14 days after injury, thus describing the chronic phase of SCI, showed that individuals with SCI did not have a higher incidence of cardiac arrhythmias compared with able-bodied controls. Furthermore, their heart rate did not differ significantly. Penile vibro-stimulation was the procedure investigated most likely to cause bradycardia, which in turn was associated with episodes of autonomic dysreflexia. The incidence of bradycardia was found to be 17–77% for individuals with cervical SCI. For individuals with thoracolumbar SCI, the incidence was 0–13%.

Conclusion: Bradycardia was commonly seen in the acute stage after SCI as well as during procedures such as penile vibro-stimulation and tracheal suction. These episodes of bradycardia were seen more often in individuals with cervical injuries. Longitudinal studies with continuous electrocardiogram recordings are needed to uncover the true relation between cardiac arrhythmias and SCI.

Keywords: Cardiac arrhythmia, Bradycardia, Tachycardia, Spinal cord injuries, Electrocardiogram, Vibro-stimulation, Tracheal suction, Tracheal intubation, Atrial fibrillation, Autonomic dysreflexia

Introduction

If uncontrolled by the autonomic nervous system, the human heart beats at a rate of approximately 100 beats per minute (bpm),¹ which is the spontaneous rate produced by the pacemaker cells in the sinoatrial node situated in the wall of the right atrium. During rest the normal heart rate (HR) is considerably lower reflecting the inhibiting action of the parasympathetic tone.² The parasympathetic fibers, controlling the heart, exit the central nervous system at brain stem level, i.e. the vagal nerve (cranial nerve X). In contrast, the sympathetic control of the heart originates from the upper thoracic spinal cord segments (Th1–Th5). A

trauma to the cervical region of the spinal cord will therefore typically only influence the spinal sympathetic neurons involved in heart regulation. It is known that sympathetic and parasympathetic innervations typically function in opposition to each other. Parasympathetic action depresses the HR, while activation of sympathetic nervous system results in increase in HR and stroke volume to increase the cardiac output when needed.

Unopposed parasympathetic control is believed to cause episodes of marked bradycardia and asystolia. Injuries that damage the spinal sympathetic pathways that control the heart and maintain the vascular tone below the level of spinal cord injury (SCI) are more likely to result in neurogenic shock and of developing HR abnormalities that could contribute to early mortality following SCI.³ It is therefore important to be

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aware of this additional cardiovascular challenge when investigating cardiac arrhythmias after SCI.

The ultimate goal is to be able to identify patients in need of aggressive pharmacological therapy and temporary or permanent cardiac pacemaker soon after injury. These therapies, in combination with vascular support, could potentially avoid life-threatening neurogenic shock in the acute phase of SCI.

The incidence of cardiac arrhythmias among individuals with SCI remains unclear, especially in the group of individuals with thoracic injuries. If clinicians could stratify patients by high and low risk for cardiac arrhythmias and death after SCI, lives could perhaps be saved. The aim is therefore to review the incidence of cardiac arrhythmias among individuals with traumatic SCI reported in the literature, including the possible effect of the level and the severity of the spinal cord lesion.

Method

In January and June 2011 and in August 2012, MEDLINE searches were carried out using the search terms (arrhythmias, cardiac OR electrocardiography) AND (paraplegia OR spinal cord injury OR tetraplegia OR quadriplegia).

After filtering out all non-English articles, this rendered 304 hits.

Inclusion criteria required that the articles (1) contained original data, (2) on cardiac arrhythmias, (3) in humans, with (4) traumatic SCI.

Arrhythmias were defined according to The Minnesota Code Classification System⁴. If the author's definition of bradycardia differed from the 'below 50 bpm' standard stated by The Minnesota Code Classification System, then the authors' definition was reported with the result of the study. Therefore, the definitions of bradycardia presented in Tables 1–3 are not always the same, occasionally making direct comparison impossible. Among the 304 articles were 19 reviews and 24 animal studies. After considering the titles of the 261 remaining articles, 175 were excluded because they were not found to be relevant. The articles were excluded if the title indicated that the studied illness was anything else than SCI or if the objective was to study the effect of a medication. Articles that tested the efficiency of surgery or surgical implants were likewise excluded. If there was any doubt to the relevance of the article, the abstract was read.

The abstracts of the remaining 86 articles were read, and 40 additional articles were excluded because the content was not relevant for the review.

The 46 remaining articles were all read *in extenso* and 24 of these were found to meet the inclusion criteria of

this review. The reference lists of the original articles, as well as the reviews were hand searched for possible relevant articles, but no additional references were found this way. Finally, we made several MEDLINE searches which in different constellations combined the search terms: spinal cord injury with pace maker, arrhythmias, tachycardia, bradycardia, heart block, atrial flutter, and autonomic dysreflexia. This search resulted in the inclusion of eight more articles referred to as 'free-search' in the flow diagram (Fig. 1).

The original articles were divided into three categories:

Studies that covered the time 1–14 days after the SCI were placed in the acute category.

Articles with results that did not cover the first 2 weeks after SCI were placed in the chronic category.

Articles describing arrhythmia occurring in direct relation to, for example, tracheal suctioning, exercise, or penile vibro-stimulation were placed in the specific exposure category.

Data from articles in the specific exposure category often covered resting arrhythmias before the exposure. Those data also appear in the chronic category.

The results were presented according to the level or severity of neurological injury, or both. The level of neurological injury was referred to as cervical if it included the neck region, as thoracic if the chest region was involved and as lumbo-sacral if the lowest part of the spinal cord was injured. To present the severity of injury, the American Spinal Injury Association (ASIA) Impairment Scale (AIS)⁵ or the Frankel Grade⁶ are reported in accordance with the scale used.

Results

Acute

All articles in the acute category (Table 1) found bradycardia in patients with acute cervical SCI.^{7–13} Lehmann *et al.*⁹ also found a trend related to the Frankel grade, i.e. individuals with more severe cervical injuries (Frankel A–B) had a higher incidence of bradycardia than those with less severe cervical injuries (Frankel C–D). Piepmeier *et al.*¹² found a similar trend. Winslow *et al.*¹³ reported 22 cases of bradycardia in a population of 374 patients with SCI. For all of the results mentioned above the bradycardia was self-limiting within 3–5 weeks and peaked at day 4–6 after injury (Fig. 2).

Supraventricular tachycardia was found in 19% of patients with severe cervical SCI with Frankel grade A and B.^{9,12} This was only reported in individuals with cervical injuries. Ventricular tachycardia, nodal rhythm, junctional premature beats, atrial fibrillation, and cardiac arrest were also seen in small numbers of

Table 1 Reported arrhythmias within the first 14 days after SCI, i.e. acute category

First author and year	Population characteristics	Results according to neurological level or severity of SCI, numbers (%)	Bradycardia defined as heart rate less than
Franga (2006) ⁷	30 Patients with cervical SCI 30 Cervical	5 (17) Bradycardia	60 bpm
Garner (1985) ⁸	10 Patients, 10 able-bodied controls 2 C5 4 C6 2 C7 2 C8 10 Controls	1 (50) Bradycardia, 1 (50) JPB 2 (50) Bradycardia (one patient with nodal rhythm, tachycardia, and atrial fibrillation) 2 (100) Bradycardia 1 (50) Bradycardia *	60 bpm
Guly (2007) ¹¹	301 Patients with cervical SCI 301 Cervical	75 (25) Bradycardia	60 bpm
Lehmann (1987) ⁹	71 Patients 31 Frankel A + B cervical 17 Frankel C + D cervical 23 Frankel A – E Thoracolumbar	31 (100) Bradycardia, 6 (19) supraventricular tachycardia, 2 (6) ventricular tachycardia, 5 (16) cardiac arrest 6 (35) Bradycardia 3 (13) Bradycardia	60 bpm
Moerman (2011) ¹⁰	106 Patients with cervical SCI 106 Cervical	15 (14) Bradycardia	60 bpm
Piepmeyer (1985) ¹²	45 Patients with cervical SCI 31 Frankel A + B 14 Frankel C + D	25 (81) Bradycardia, 6 (19) supraventricular tachycardia, 2 (6) ventricular tachycardia 4 (29) Bradycardia 1 (7), supraventricular tachycardia	50 bpm
Winslow (1986) ¹³	374 Patients 83 Complete cervical injury 153 In-complete cervical injury 98 Thoracic 40 Lumbar	22 (26) Bradycardia * 0 (0) Bradycardia 0 (0) Bradycardia	50 bpm

JPB, junctional premature beat.

*Incidence of arrhythmias not reported for this group.

patients with acute cervical SCI (Table 1). For studies defining bradycardia as HR less than 60 bpm, the incidence was 14–77% for individuals with cervical SCI. The same incidence was 26–64% for studies using HR less than 50 bpm as definition of bradycardia (see Table 1). The incidence of other arrhythmias was 18–27% and 0% for individuals with cervical and thoracolumbar SCI, respectively.

Chronic

In the chronic category (Table 2) the results were less uniform.^{14–19} The two articles by Claydon *et al.*^{15,16} were the only examples in the chronic category that reported data on bradycardia. The study samples were small, but they found that 26–50% of the individuals with cervical and 13–60% of the individuals with thoracic SCI presented with bradycardia. All studies, that used bradycardia as variable, defined this as HR less than 60 bpm. Likewise ventricular premature beats (VPB) were frequent, although Prakash *et al.*¹⁹ reported that VPB was not more common among individuals with SCI than in able-bodied controls. Prakash *et al.*¹⁹ used computerized analysis to identify electrocardiogram

(ECG) abnormalities in 654 patients with chronic SCI, and compared the result with those of 26 734 able-bodied controls. They reported that individuals with chronic SCI had no greater risk of having atrial fibrillation than the able-bodied controls. The level of neurological injury had no effect on atrial fibrillation or VPB in their study. The SCI group and the able-bodied controls did not differ significantly in mean HR.¹⁹ Leaf *et al.*¹⁸ made follow-ups on 47 patients with cervical, thoracic, and lumbar SCI during a 2-year period without finding any ‘clinical significant’ arrhythmias.

Specific exposure

In the specific exposure category (Table 3) the authors studied the response in HR to various stimuli including effects of exercise, penile vibro-stimulation, tracheal suction and intubation, facial water-immersion, and tilting in individuals with SCI.^{8,15,16,20–26} Claydon *et al.*¹⁵ reported that 6 of 13 male participants with cervical SCI developed new bradycardia when undergoing penile vibro-stimulation for sperm retrieval. Furthermore, some of these participants had episodes of atrial premature beats and VPB during or after the

Table 2 Reported arrhythmias after the first 14 days after SCI, i.e. chronic category

First author and year	Population characteristics	Results according to neurological level and severity of SCI, numbers (%)	Bradycardia defined as heart rate less than
Claydon (2006) ¹⁵	27 patients 19 AIS A 7 AIS B 1 AIS C 19 Cervical 8 Thoracic	5 (26) Bradycardia (one patient had tachycardia and VPB) 1 (14) Bradycardia 0 (0) Bradycardia 5 (26) Bradycardia 1 (13) Bradycardia (one patient had tachycardia and VPB)	60 bpm
Claydon (2006) ¹⁶	13 male patients 8 AIS A 3 AIS B 2 AIS C 8 Cervical 5 Thoracic	3 (38) Bradycardia (one patient also had VPB and APB) 3 (100) Bradycardia, 1 (50) Bradycardia 4 (50) Bradycardia 3 (60) Bradycardia (one patient also had VPB and APB)	60 bpm
Blocker (1983) ¹⁴	98 Patients 41 Cervical, 44 Thoracic 4 Lumbar 9*	Not indicated who had the cardiac arrhythmias. 2 (2% of 98) VPB	**
Kessler (1986) ¹⁷	14 patients, 7 controls 7 Cervical 7 Thoracic 7 Controls	No arrhythmias found	**
Leaf (1993) ¹⁸	47 patients 25 Cervical 17 Thoracic 5 Lumbar	4 (16) VPB 1 (20) VPB	**
Prakash (2002) ¹⁹	654 Patients and 26734 controls 394 Th5 and above 260 Th6 and below 26734 Able-bodied controls	7 (2) Atrial fibrillation, 7 (2) VPB 2 (1) Atrial fibrillation, 5 (2) VPB 727 (3) Atrial fibrillation, 1170 (4) VPB	**

AIS, American Spinal Injury Association Impairment Scale; JPB, junctional premature beat; VPB, ventricular premature beats; APB, atrial premature beat.

*Patients not found in other groups.

**Bradycardia not used or not systematically reported in these studies.

procedure. The severity or level of neurological injury had no influence on the results of this study.

Yoo *et al.*²⁶ divided their 214 participants in to groups categorized by level and time after injury (Table 3). They reported that individuals, with acute SCI <4 weeks, developed bradycardia more often than able-bodied controls, when being intubated before surgery. The participants with acute cervical injury developed bradycardia more often than the participants with acute injury below Th5. The participants with injuries older than 4 weeks did not develop bradycardia more often than the able-bodied controls, but individuals with chronic and low injuries had higher incidences of tachycardia after intubation.

Case reports

Bradycardia was the most commonly reported arrhythmia in the case reports, but tachycardia, atrial, and ventricle fibrillation were also reported.^{27–38} The majority

of cases of arrhythmia were reported during episodes of autonomic dysreflexia among individuals with cervical SCI. The patients were between 16 and 60 years of age and all were male. Bradycardia was often seen and Welply *et al.*³⁸ even reported two cases of cardiac arrest during tracheal suction. But spontaneous events of bradycardia were also reported. All except one³⁰ described that the participants had permanent or temporary pacemaker insertion.

Discussion

This review provides further evidence that bradycardia is a common problem among individuals with acute SCI. However, not much can be concluded about the relationship between other cardiac arrhythmias and SCI. Some studies, in the acute category, reported supraventricular tachycardia, ventricular tachycardia, and even cardiac arrest in patients with cervical injuries. None of the arrhythmias mentioned above were found

Table 3 Arrhythmias in individuals with spinal cord injury exposed to specific provocations

First author and year	Population characteristics	New arrhythmias during/after exposure, numbers (%)	Provocation	Bradycardia defined as heart rate less than
Claydon (2006) ¹⁶	27 patients 19 AIS A 7 AIS B 1 AIS C 19 Cervical 8 Thoracic	No clinically significant changes compared with the resting electrocardiographic activity?	Arm cycling exercise	60 bpm
Claydon (2006) ¹⁵	13 male patients 8 AIS A 3 AIS C 2 AIS C 8 Cervical 5 Thoracic	5 (63) Bradycardia, 3 (38) VPB, 3 (38) APB 3 (67) VPB 2 (67) APB 1 (50) Bradycardia 4 (50) Bradycardia, 4 (50) APB, 1 (13) VPB 2 (40) Bradycardia, 1 (20) VPB	Penile vibro-stimulation	60 bpm
Dollfus (1965) ²⁰	7 patients 6 Cervical 1 Thoracic	No arrhythmias found	Tracheal suction	***
Garner (1985) ⁸	10 patients cervical, 10 able-bodied controls 2 C5 4 C6 2 C7 2 C8 10 Controls	No new arrhythmias reported	Facial water immersion	***
Guttmann (1963) ²¹	17 patients 7 Cervical 10 Thoracic	No arrhythmias reported	Tilting	***
Hopman (1992) ²²	11 patients, 11 controls 11 Thoracic 5 Knee and foot injured 6 Able-bodied	No arrhythmias reported	Arm exercise	***
West (2012) ²³	7 participants cervical 6 AIS A 1 AIS B	6 Tachycardia (100) 1 Tachycardia (100)	Wheelchair exercise	***
Yoo (2001) ²⁴	54 patients, 20 controls 22 Cervical 8 Thoracic T1–T4 24 Thoracic below T5 20 Controls	1 (5) Bradycardia, 1 (5) tachycardia, 1 (5) dysrhythmias 2 (25) Bradycardia, 6 (75)* tachycardia, 2 (25) dysrhythmias 0 (0) Bradycardia, 8 (33)* tachycardia, 4 (17) dysrhythmias 0 (0) Bradycardia, 3 (15) tachycardia, 2 (10) dysrhythmias	Laryngoscopy	60 bpm
Yoo (2003) ²⁵	160 patients, 25 controls 26 Cervical <4 weeks 27 Cervical >4 weeks 24 Below T5 <4 weeks 29 Below T5 >4 weeks 25 Controls	12 (46)* Bradycardia, 0 (0) tachycardia, 1 (4) dysrhythmias 2 (7) Bradycardia, 2 (7) tachycardia, 2 (7) dysrhythmias 1 (4) Bradycardia, 6 (25) tachycardia, 4 (17) dysrhythmias 3 (10) Bradycardia, 14 (48)* tachycardia, 4 (14) dysrhythmias 2 (8) Bradycardia, 3 (12) tachycardia, 2 (8) dysrhythmias	Tracheal intubation	60 bpm
Yoo (2010) ²⁶	214 Patients, 20 able-bodied controls 27 Cervical <4 weeks 23 Below T5 <4 weeks 14 Cervical 4 weeks–1 year 21 Below T5 4 weeks–1 year 9 Cervical 1–5 years	9 (33)* Bradycardia, 0 (0) tachycardia, 2 (7) dysrhythmias 2 (9)** Bradycardia, 3 (13) tachycardia, 3 (13)** dysrhythmias 1 (7) Bradycardia, 2 (14) tachycardia, 1 (7) dysrhythmias 1 (5) Bradycardia, 7 (33)* tachycardia, 1 (5) dysrhythmias 2 (22) Bradycardia, 2 (22) tachycardia, 0 (0) dysrhythmias	Tracheal intubation	60 bpm

Continued

Table 3 Continued

First author and year	Population characteristics	New arrhythmias during/after exposure, numbers (%)	Provocation	Bradycardia defined as heart rate less than
22	Below T5 1–5 years	2 (9) Bradycardia, 11 (50)* tachycardia, 1 (5) dysrhythmias		
10	Cervical 5–10 years	1 (10) Bradycardia, 0 (0) tachycardia, 1 (10) dysrhythmias		
30	Below T5 5–10 years	4 (13) Bradycardia, 11 (37)* tachycardia, 2 (7) dysrhythmias		
10	Cervical 10–20 years	1 (10) Bradycardia, 0 (0) tachycardia, 2 (20) dysrhythmias		
29	Below T5 10–20 years	4 (14) Bradycardia, 8 (28) tachycardia, 3 (7) dysrhythmias		
1	Cervical >20 years	0 (0) Bradycardia, 0 (0) tachycardia, 0 (0) dysrhythmias		
18	Below T5 >20 years	2 (9) Bradycardia, 3 (13) tachycardia, 3 (13) dysrhythmias		
20	Controls	2 (11) Bradycardia, 1 (6) tachycardia, 3 (10) dysrhythmias		

AIS, American Spinal Injury Association Impairment Scale; JPB, junctional premature beat; VPB, ventricular premature beats; APB, atrial premature beat; dysrhythmia, ventricular or supraventricular premature beat or any sustained rhythm other than sinus.

* $P < 0.05$ vs. control group.

** $P < 0.05$ vs. cervical group.

***Definition of bradycardia used, not stated in the article.

Figure 1 Flow diagram showing the process towards the final inclusion of articles for the review. Free search refers to a series of searches combining different relevant search terms in the MEDLINE database. (+1) The acute category (Table 1) contains one article also present in the specific exposure category. (+2) The chronic category (Table 2) contains two articles also present in the specific exposure category.

Figure 2 Incidence of bradycardia within the first 14 days after spinal cord injury.

in patients with thoracic injuries or in any control group. This could be a coincidence but it could also be a sign of the autonomic instability that is often seen after SCI to the cervical region¹² or by episodes of autonomic dysreflexia. The severity of injury seems to influence the risk of bradycardia, for persons with cervical injuries in the acute stage.^{9,12,39} This could likewise be explained by the autonomic imbalance of the heart rate control after SCI.⁹ After high-level SCI the spinal sympathetic pathways involved in maintaining HR are disrupted, leaving the heart with unopposed parasympathetic vagal tone⁴⁰. This imbalance creates vulnerability to exogenous stimuli such as tracheal suction,²⁶ but also to spontaneous episodes of bradycardia.⁹ The incidence of bradycardia peaked at days 4–6^{8,9,12} (Fig. 2) and were self limiting within 2–6 weeks after injury.^{9,13} The largest study published to date showed that individuals with chronic SCI were not at greater risk of having cardiac arrhythmia nor did they have a lower resting HR than persons with intact CNS.¹⁹ In this study the level and severity of SCI had no influence on the prevalence of arrhythmias in the chronic stage.¹⁹

It has been documented previously that a patient with SCI and no history of heart disease experienced atrial fibrillation after sperm retrieval by penile vibro-stimulation.³⁴ Claydon *et al.*¹⁵ documented this procedure to be the most arrhythmogenic studied in this review, inducing bradycardia in 63% and VPB in 38% of the individuals with complete SCI (AIS A) (Table 3). The majority of individuals (10 out of the 13 participants) showed marked increase in mean arterial blood pressure, indicating that ejaculation induced autonomic dysreflexia (systolic blood pressure increase by >20 mmHg). Many of the men were unaware of these changes. For safety reasons, Claydon *et al.*¹⁵ therefore suggest that individuals with SCI should be appropriately monitored during penile vibro-stimulation for sperm retrieval.

A pacemaker implantation was required in up to 17% (2–17%) of all patients with cervical injuries.^{7,41,42} This large variation could result from small study samples or perhaps different clinical adherence in pacemaker implantation guidelines. Patients who received a pacemaker were characterized by a high level of injury; all but one had a neurological lesion above C5.^{7,41,42} Most bradyarrhythmias occurred during tracheal suction, events of hypoxia or when being turned in bed but spontaneous events of bradycardia were also recorded.⁷ Four out of the 10 cases described in three studies died before discharge from the hospital.^{7,41,42} Individuals with SCI have increased mortality due to cardiovascular causes in the chronic stage.⁴³ Some of these events could be the result of cardiac arrhythmias induced by autonomic dysreflexia.

Limitations

The incidence of bradycardia reported in the reviewed studies ranged between 14–77% and 26–64% depending on the definition of bradycardia used, i.e. HR <50 bpm or HR <60 bpm, respectively. The lack of a clearer difference in this respect is somewhat unexpected but visualizes the challenge of comparing data across small and heterogeneous studies. Franga *et al.*⁷ reported only clinically significant bradycardia. They therefore reported the incidence of bradycardia to be only 17%. In contrast, Lehmann *et al.*⁹ labeled all individuals who had a record of a mean HR under 60 bpm during at least 1 day as bradycardic resulting in a reported incidence of 77% for individuals with cervical injuries. These differences clearly show the importance of using international accepted standards. According to the International Standards on Autonomic Function after SCI HR <60 bpm is defined as bradycardia² but others used the definition of <50 bpm stated by the Minnesota Code Classification System⁴. The American Heart Association's recommendations⁴⁴ state that bradycardia is defined as <60 bpm but, this rate is considered normal in healthy well-trained individuals. This will lead to an overestimation of the incidence of clinically significant bradycardia.

Kessler *et al.*¹⁷ use the term 'level of spinal injury' which makes it unclear if they refer to the neurological injury to the spinal cord or to the level of fracture to the spine. All other articles in this review use the term 'spinal cord injury' making it clearer that it is the neurological injury that is described.

Many drugs influence the electrical conduction of the heart. The arrhythmogenic effects of atropine and dopamine may explain the episodes of supraventricular tachycardia seen in patients with acute SCI.⁴⁵ These

drugs were commonly used to manage bradycardia and hypotension in these patients.^{9,12,46} Tricyclic anti-depressants, commonly used to manage neuropathic pain in individuals with SCI,⁴⁷ may also influence the HR by inducing cardiac conduction delays. Some authors excluded participants who took medication that influences HR, had known diabetes mellitus, or had a history of cardiovascular disease prior to SCI. Four authors did not report on participant's medical history or medication.^{7,8,13,14} This could mean that the arrhythmias recorded as associated with SCI were present before the injury or were adverse effects of pharmacological therapy. For this reason it may as well be advisable in future studies to use the International SCI Cardiovascular Function Basic Data Set⁴⁸ to make sure this information is standardized.

Most studies did not use continuous methods to record the HR or ECG. The authors using continuous measures^{15,16} only recorded for short periods up to 1 hour. There is therefore a great risk of underestimating the incidence of both bradycardia and other arrhythmic events. Although never stated one may assume that most authors used the short-term ECG recording to determine the HR.

In this review, language bias could be a problem since all non-English articles were filtered out.

Conclusion

Bradycardia is seen frequently in the acute period after SCI among individuals with cervical injuries. The incidence of bradycardia peaks at 4–6 days after injury and is usually self-limiting after 3–5 weeks. In the chronic period after SCI, and at rest, cardiac arrhythmias are not more common among individuals with SCI than among able-bodied controls. When individuals with injuries to the spinal cord were introduced to exogenous stimulation, for example, tracheal suction, tracheal intubation, or penile vibro-stimulation, many reacted with bradycardia, and case-studies report episodes of autonomic dysreflexia and even cardiac arrest. There are still too little data in this area to produce a well-defined cut-off level for appropriate early cardiac intervention. We lack continuous and longitudinal data that records all arrhythmic events in individual patients from the acute period and through out the chronic phase.

References

- 1 Marconi C. Pathophysiology of cardiac transplantation and the challenge of exercise. *Int J Sports Med* 2000;21(Suppl 2): 106–8.
- 2 Alexander MS, Biering-Sorensen F, Bodner D, Brackett NL, Cardenas D, Charlifue S, *et al.* International standards to document remaining autonomic function after spinal cord injury. *Spinal Cord* 2009;47(1):36–43.
- 3 Collins HL, Rodenbaugh DW, DiCarlo SE. Spinal cord injury alters cardiac electrophysiology and increases the susceptibility to ventricular arrhythmias. *Prog Brain Res* 2006;152:275–88.
- 4 Prineas R. The Minnesota Code manual of electrocardiographic findings: standards and procedures for measurement and classification. Boston, MA: J. Wright; 1982.
- 5 Kirshblum SC, Burns SP, Biering-Sorensen F, Donovan W, Graves DE, Jha A. International standards for neurological classification of spinal cord injury. *J Spinal Cord Med* 2011;34(6):535–46.
- 6 Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, Ungar GH, *et al.* The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. I. *Paraplegia* 1969;7(3):179–92.
- 7 Franga DL, Hawkins ML, Medeiros RS, Adewumi D. Recurrent asystole resulting from high cervical spinal cord injuries. *Am Surg* 2006;72(6):525–9.
- 8 Garner SH, Bloch RF, Sutton JR. Heart rate response to facial immersion and apnea in quadriplegia. *Arch Phys Med Rehabil* 1985;66(11):763–7.
- 9 Lehmann KG, Lane JG, Piepmeier JM, Batsford WP. Cardiovascular abnormalities accompanying acute spinal cord injury in humans: incidence, time course and severity. *J Am Coll Cardiol* 1987;10(1):46–52.
- 10 Moerman JR, Christie BD 3rd, Sykes LN, Vogel RL, Nolan TL, Ashley DW. Early cardiac pacemaker placement for life-threatening bradycardia in traumatic spinal cord injury. *J Trauma* 2011; 70(6):1485–8.
- 11 Guly HR, Bouamra O, Lecky FE. The incidence of neurogenic shock in patients with isolated spinal cord injury in the emergency department. *Resuscitation* 2008;76(1):57–62.
- 12 Piepmeier JM, Lehmann KB, Lane JG. Cardiovascular instability following acute cervical spinal cord trauma. *Cent Nerv Syst Trauma* 1985;2(3):153–60.
- 13 Winslow EB, Lesch M, Talano JV, Meyer PR. Spinal cord injuries associated with cardiopulmonary complications. *Spine* 1986;11(8): 809–12.
- 14 Blocker WP, Merrill JM, Krebs MA, Cardus DP, Ostermann HJ. An electrocardiographic survey of patients with chronic spinal cord injury. *Am Correct Ther J* 1983;37(4):101–4.
- 15 Claydon VE, Elliott SL, Sheel AW, Krassioukov A. Cardiovascular responses to vibrostimulation for sperm retrieval in men with spinal cord injury. *J Spinal Cord Med* 2006;29(3): 207–16.
- 16 Claydon VE, Hol AT, Eng JJ, Krassioukov AV. Cardiovascular responses and postexercise hypotension after arm cycling exercise in subjects with spinal cord injury. *Arch Phys Med Rehabil* 2006; 87(8):1106–14.
- 17 Kessler KM, Pina I, Green B, Burnett B, Laighold M, Bilsker M, *et al.* Cardiovascular findings in quadriplegic and paraplegic patients and in normal subjects. *Am J Cardiol* 1986;58(6): 525–30.
- 18 Leaf DA, Bahl RA, Adkins RH. Risk of cardiac dysrhythmias in chronic spinal cord injury patients. *Paraplegia* 1993;31(9):571–5.
- 19 Prakash M, Raxwal V, Froelicher VF, Kalisetti D, Vieira A, O'Mara G, *et al.* Electrocardiographic findings in patients with chronic spinal cord injury. *Am J Phys Med Rehabil* 2002;81(8): 601–8.
- 20 Dollfus P, Frankel HL. Cardiovascular reflexes in tracheostomised tetraplegics. *Paraplegia* 1965;2:227–35.
- 21 Guttman L, Munro AF, Robinson R, Walsh JJ. Effect of tilting on the cardiovascular responses and plasma catecholamine levels in spinal man. *Paraplegia* 1963;1:4–18.
- 22 Hopman MT, Oeseburg B, Binkhorst RA. Cardiovascular responses in paraplegic subjects during arm exercise. *Eur J Appl Physiol Occup Physiol* 1992;65(1):73–8.
- 23 West CR, Mills P, Krassioukov AV. Influence of the neurological level of spinal cord injury on cardiovascular outcomes in humans: a meta-analysis. *Spinal Cord* 2012;50(7):484–92.
- 24 Yoo KY, Lee JU, Kim HS, Im WM. Hemodynamic and catecholamine responses to laryngoscopy and tracheal intubation in patients with complete spinal cord injuries. *Anesthesiology* 2001; 95(3):647–51.

- 25 Yoo KY, Jeong SW, Kim SJ, Ha IH, Lee J. Cardiovascular responses to endotracheal intubation in patients with acute and chronic spinal cord injuries. *Anesth Analg* 2003;97(4):1162–7.
- 26 Yoo KY, Jeong CW, Kim SJ, Jeong ST, Kwak SH, Shin MH, *et al*. Altered cardiovascular responses to tracheal intubation in patients with complete spinal cord injury: relation to time course and affected level. *Br J Anaesth* 2010;105(6):753–9.
- 27 Colachis SC, Clinchot DM. Autonomic hyperreflexia associated with recurrent cardiac arrest: case report. *Spinal Cord* 1997;35(4):256–7.
- 28 Forrest GP. Atrial fibrillation associated with autonomic dysreflexia in patients with tetraplegia. *Arch Phys Med Rehabil* 1991;72(8):592–4.
- 29 Johnson CD, Perea López RM, Rodríguez L. Acute spinal cord and head injury: case report and discussion of cardiac, respiratory and endocrine abnormalities. *Bol Assoc Med P R* 1998;90(4–6):95–101.
- 30 Mathias CJ. Bradycardia and cardiac arrest during tracheal suction—mechanisms in tetraplegic patients. *Eur J Intensive Care Med* 1976;2(4):147–56.
- 31 Pine ZM, Miller SD, Alonso JA. Atrial fibrillation associated with autonomic dysreflexia. *Am J Phys Med Rehabil* 1991;70(5):271–3.
- 32 Ruiz-Arango AF, Robinson VJB, Sharma GK. Characteristics of patients with cervical spinal injury requiring permanent pacemaker implantation. *Cardiol Rev* 2006;14(4):e8–e11.
- 33 Sanghvi AV, Chhabra HS, Nigam V, Tandon V, Mascarenhas AA. Permanent cardiac pacemaker for cardiac arrest following cervico-dorsal spinal injury. *Eur Spine J* 2009;18(Suppl 2):254–7.
- 34 Scheutzw MH, Bockenek WL. An unusual complication during electroejaculation in an individual with tetraplegia. *J Spinal Cord Med* 2000;23(1):28–30.
- 35 Silbert PL, Davis JM. Late asystole in high cervical spinal cord injury: case report. *Paraplegia* 1990;28(2):137–40.
- 36 Singh A, Garg R, Weachter R. Cardiac bradyarrhythmias in a patient with cervical spine injury. *Am Heart Hosp J* 2010;8(1):63–5.
- 37 Velnar T, Smrkolj V, Cerovic O, Pecaric Meglic N, Tauscher G. An unusual case of high cervical spinal cord injury. *Folia Neuropathol* 2010;48(2):134–8.
- 38 Welpy NC, Mathias CJ, Frankel HL. Circulatory reflexes in tetraplegics during artificial ventilation and general anaesthesia. *Spinal Cord* 1975;13(3):172–82.
- 39 Dixit S. Bradycardia associated with high cervical spinal cord injury. *Surg Neurol* 1995;43(5):514.
- 40 Weaver LC, Fleming JC, Mathias CJ, Krassioukov AV. Disordered cardiovascular control after spinal cord injury. *Handb Clin Neurol* 2012;109:213–33.
- 41 Bilello JF. Cervical spinal cord injury and the need for cardiovascular intervention. *Arch Surg* 2003;138(10):1127–9.
- 42 Rangappa P, Jeyadoss J, Flabouris A, Clark JM, Marshall R. Cardiac pacing in patients with a cervical spinal cord injury. *Spinal Cord* 2010;48(12):867–71.
- 43 Garshick E, Kelley A, Cohen SA, Garrison A, Tun CG, Gagnon D, *et al*. A prospective assessment of mortality in chronic spinal cord injury. *Spinal Cord* 2005;43(7):408–16.
- 44 American Heart Association. Sinus disturbances [Internet]. [cited 2011 Feb 21]. Available from: <http://www.americanheart.org/presenter.jhtml?identifier=55>.
- 45 Tamargo J, Caballero R, Gómez R, Barana A, Amorós I, Delpón E. Investigational positive inotropic agents for acute heart failure. *Cardiovasc Hematol Disord Drug Targets* 2009;9(3):193–205.
- 46 Ball PA. Critical care of spinal cord injury. *Spine* 2001;26(24 Suppl):S27–30.
- 47 Teasell RW, Mehta S, Aubut J-AL, Foulon B, Wolfe DL, Hsieh JTC, *et al*. A systematic review of pharmacologic treatments of pain after spinal cord injury. *Arch Phys Med Rehabil* 2010;91(5):816–31.
- 48 Krassioukov A, Alexander MS, Karlsson A-K, Donovan W, Mathias CJ, Biering-Sørensen F. International spinal cord injury cardiovascular function basic data set. *Spinal Cord* 2010;48(8):586–90.