ORIGINAL ARTICLE

Cardiac pacing in patients with a cervical spinal cord injury

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Study design: Retrospective medical record review.

Objectives: To compare patients, admitted to an intensive care unit (ICU) with an acute cervical spinal cord injury (SCI) and documented motor deficit, who did, with those who did not, require a cardiac pacemaker.

Setting: South Australian Tertiary Referral Intensive Care and Spinal Injury Unit.

Methods: Retrospective medical record review and data set linkage.

Results: From 1995 to 2007, 465 patients sustained a cervical SCI. Of these, 30 (6.5%) were admitted to ICU with a clinically assessable motor deficit and 3 (0.6% of all patients, or 10% of those admitted to ICU) required a cardiac pacemaker. All three patients had a cervical SCI, C5 (American Spinal Injury Association A) tetraplegia, and required invasive mechanical respiratory and inotropic support and a tracheostomy for weaning. Two patients (66%) were discharged alive to rehabilitation. Patients requiring a pacemaker had bradycardic episodes over a longer period (11 vs 4 days, $P=0.01$), a trend towards a later onset of bradycardia (8 vs 1.5 days, $P=0.05$) and a longer ICU length of stay (37 vs 10 days, $P=0.02$).

Conclusion: Patients with a cervical SCI requiring a cardiac pacemaker are characterized by a higher level of SCI injury and motor loss, require mechanical respiratory and inotropic support, a tracheostomy to wean, and bradycardic episodes of a later onset and over a longer period of time. These findings suggest that such patients should be managed at hospitals with specialized acute spinal injury, intensive care and cardiac pacemaker services.

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Introduction

Cardiovascular instability is common following a cervical spinal cord injury (SCI).¹ Bradycardia is almost universal, and a cardiac arrest occurs in up to 15% of such patients.^{2,3} Typically, the frequency and severity of bradycardia are directly related to the severity of the cervical SCI, highest within the 3- to 5-day period following a cervical SCI, and declines rapidly 2 weeks after injury.³ The disruption of supraspinal sympathetic pathways, and the resultant parasympathetic dominance, as a consequence of a cervical SCI is the major cause of cardiovascular instability.^{4,5} This effect may persist for weeks.^{3,6} The occurrence of cardiovascular instability is also influenced by factors other than the severity of the SCI such as hypoxia, endotracheal suctioning and other physical stimuli.^{3,7–10} Bradycardia and

in its severest manifestation, asystole, are significant contributors to poor patient outcomes, as cardiac events are the main cause of death in the first year following cervical SCI.^{9,10}

Treatment of life-threatening bradycardia in SCI generally includes oxygen, atropine, inotropes and aminophylline.^{11,12} In refractory cases, and for those associated with a life-threatening events, such as an asystolic cardiac arrest, temporary and permanent pacemakers have been used.^{3,7,11} However criteria for the optimal timing and prophylactic use of pacemakers in SCI are poorly defined. Although pacemakers are highly successful in the management of severe bradycardia and asystole, they are not however without complications.^{7,13}

The objective of this study was to describe patients with an acute cervical SCI requiring admission to an intensive care unit (ICU), and from this group, compare and contrast those patients for whom a cardiac pacemaker was deemed necessary for the management of life-threatening bradycardia with those for whom a pacemaker was not required.

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Materials and methods

We used retrospective medical record review of patients identified from the Australian Spinal Cord Injury Register to have had an acute cervical SCI, a documented motor deficit and American Spinal Injury Association (ASIA) classification¹³ and admitted to the Royal Adelaide Hospital ICU within 48 h of the injury.

Study variables

Patient and injury features were: age, gender, level of SCI, ASIA classification, referral source being another hospital, operation and approach (anterior, posterior), documented bradycardia (pulse <45 beats per min) and documented bradycardia precipitants, Acute Physiology Assessment and Chronic Health Evaluation II (APACHE II) score,¹⁴ ICU and acute hospital discharge status.

ICU interventions were: inotropes by infusion for indications other than just bradycardia, pharmacological interventions for bradycardia, invasive mechanical respiratory support, tracheostomy and pacemaker.

All time periods begin from the date of the acute injury.

Statistical method

Statistical analysis consisted of descriptive tests; Mann–Whitney for continuous data and χ^2 -analysis (only where all cells >5). Statistical significance was set at $P < 0.05$.

Results

From the years 1995 to 2007, 465 patients within South Australia sustained a cervical SCI. Of these, 30 (6.5%) patients were admitted to ICU at the acute phase of their injury. Their demographic, illness and management features are listed in Table 1. Of the patients who had operative management of their cervical SCI, 52.4% received so within 48 h of injury (71.4% by an anterior approach). All patients received invasive mechanical respiratory support, of which 17 (56.7%) received a tracheostomy, all of whom survived, and 3 (17.6%) of whom were still ventilator dependent at discharge from the acute hospital. Median length of

mechanical respiratory support for survivors successfully weaned from mechanical ventilation was 13 (range 1, 37) days. Patients who survived their ICU admission also were alive at the time of acute hospital discharge.

Overall, 15 (50%) patients had a documented episode of bradycardia (pulse <45 beats per min). Of these, 13 (88%) were receiving inotropes by infusion for indications other than bradycardia alone, and 10 (66.7%) received an intervention specifically for bradycardia (atropine, adrenaline bolus and/or increased rate of infusion were the only pharmacological interventions). Bradycardic episodes were more frequent in patients who did, compared with patients who did not, receive inotropes by infusion (65 vs 20%, $P = 0.02$).

Bradycardic episodes occurred from day 1 until day 17, with a median duration being 4 days. Three (10%) patients required a cardiac pacemaker for life-threatening bradycardia. All three patients had at first a temporary transvenous pacemaker (set at VVI), and subsequently, for the two survivors, a permanent dual-chamber demand pacemaker, all while in-patients in the ICU.

The clinical indication for a cardiac pacemaker in all patients was severe bradycardia, unresponsive to pharmacological intervention and leading to asystole requiring cardiopulmonary resuscitation. Before these severe episodes, all patients had shown only infrequent episodes of bradycardia not associated with documented hypotension. These antecedent episodes resolved spontaneously, or with additional oxygen therapy or pharmacological intervention (intravenous atropine). An example of a set of observations recorded in one patient is shown in Figure 1.

All three patients had a C5 or higher SCI tetraplegia, required anterior surgical fixation, inotropes by infusion, invasive mechanical respiratory support and a tracheostomy to facilitate weaning from respiratory support. Time from injury to first insertion of a pacemaker was 9, 10 and 17 days. At that time of pacemaker insertion, all three patients were receiving patient-triggered assisted mechanical ventilation. Table 2 lists further features of these patients.

Two of the patients who required a pacemaker survived to discharge from the acute hospital. Their ICU length of stay (LOS) was 38 and 62 days. One patient developed an infection of the temporary transvenous pacemaker necessitating removal and subsequent replacement of the pacemaker. For the patient who died, cause of death was respiratory failure after withdrawal of life support.

Patients who did, were compared with those that did not, require a cardiac pacemaker (Table 3). Patients who required a pacemaker had bradycardic episodes over a significantly longer period of time (11 vs 4 days, $P = 0.01$), a trend towards a later onset (8 vs 1.5 days, $P = 0.05$) and a longer ICU LOS (37 vs 10 days, $P = 0.02$).

Discussion

This study identified that the need for a cardiac pacemaker among patients with a cervical SCI is confined to those with a C5 or higher injury, tetraplegia, and requiring invasive

Table 1 Characteristics of patients with a cervical SCI and admitted to the ICU

	Patients with an SCI and admitted to the ICU (N = 30)
Age (years, median, s.d.)	40.1 (s.d. 18.7)
Male gender	27 (90%)
C5 or higher SCI	23 (76.7%)
Operative intervention	21 (70%)
APACHE II score (median, s.d.)	13 (s.d. 5)
Invasive positive pressure mechanical ventilation	30 (100%)
Inotropes by infusion for reasons other than bradycardia	21 (70%)
ICU length of stay (days, median and range)	37 (1–63)
Acute hospital mortality	6 (20%)

Abbreviations: APACHE, Acute Physiology Assessment and Chronic Health Evaluation II; ICU, intensive care unit; SCI, spinal cord injury.

Figure 1 Charting of the heart rate (red), systolic blood pressure (black) and temperature of the 43-year-old with a CSCI, while in the intensive care unit, in the hours immediately preceding the decision for, and insertion of, a cardiac pacemaker. A full colour version of this figure is available at the *Spinal Cord* online.

Table 2 Injury and clinical features of patients with a cervical SCI requiring a cardiac pacemaker

Patients	22-year-old man	37-year-old man	43-year-old man
Mechanism of injury	Assault	Motor vehicle accident	Pedestrian hit by train
Spinal injury	C4/5 spinal fracture and dislocation	C4/5 spinal fracture and dislocation	C4/5 spinal fracture and dislocation
Level of motor deficit	C5 tetraplegia, complete (ASIA-A)	C5 tetraplegia, complete (ASIA-A)	C5 tetraplegia, complete (ASIA-A)
Need for invasive respiratory mechanical ventilation	Yes, on admission	Yes, on admission	Yes, on admission
APACHE II score	15	14	22
Timing of spinal surgery (days following injury)	2	1	4
Timing of first insertion of a cardiac pacemaker (days following injury)	9	17	10
Timing of insertion of a permanent cardiac pacemaker (days following injury)	29	NA	25
Tracheostomy to wean mechanical ventilation	Yes	Yes	Yes
Duration of mechanical ventilation (days)	33	22	Still ventilated at time of acute hospital discharge
ICU length of stay (days)	38	22	63
Acute hospital length of stay (days)	134	22	232
Hospital outcome	Alive	Died	Alive
Pacemaker-related complications	Nil	Nil	Pacemaker infection requiring removal and replacement

Abbreviations: APACHE, Acute Physiology Assessment and Chronic Health Evaluation II; ASIA, American Spinal Injury Association; ICU, intensive care unit; NA, not applicable as patient died before consideration for a permanent cardiac pacemaker.

Table 3 Comparison of patients who did with those who did not require a cardiac pacemaker

	Patients with a cardiac pacemaker (N = 3)	Patients without a cardiac pacemaker (N = 27)	P-value
Male gender	100%	89%	
ASIA-A	100%	88.5%	
Operative intervention	100%	66.7%	
Inotropes by infusion	100%	66.7%	
Tracheostomy	100%	51.8%	
Survive to hospital discharge	66.7%	81.5%	
Age (years, median)	37.8 (21.7, 42)	40.6 (15.1, 86.7)	0.51
APACHE II score (median)	14 (12, 15)	13 (2, 26)	0.56
Day of onset of bradycardia (median, range)	8 (1, 9)	1.5 (1, 6)	0.05
Days with bradycardic episodes (median, range)	11 (9, 16)	4 (1, 10)	0.01
ICU length of stay (days, median)	37 (22, 63)	10 (1, 55)	0.02

Abbreviations: APACHE, Acute Physiology Assessment and Chronic Health Evaluation II; ASIA, American Spinal Injury Association; ICU, intensive care unit.

mechanical respiratory and inotropic support. The features that best distinguished patients requiring a pacemaker were bradycardic episodes over a longer period of time and of a later onset. Overall, patients admitted to ICU with a cervical SCI have a prolonged duration of respiratory support, long ICU LOS and most of them require a tracheostomy.

The indications for a pacemaker among our patients were episodes of severe bradycardia leading to an asystolic cardiac arrest necessitating cardiopulmonary resuscitation to stimulate the return of a spontaneous circulation. These events were sudden and, only infrequently preceded by other symptomatic bradycardic episodes, infrequently associated with an obvious precipitant, often resolved spontaneously, or following administration of oxygen or pharmacological interventions, such as atropine.

Almost all patients with a cervical SCI may experience a bradycardia, and 15% a cardiac arrest.^{2,3} Hypoxia, endotracheal suction or changes in posture can precipitate a bradycardic event.^{3,7-10} The overall frequency of bradycardia among our patients was relatively lower than reported in the literature, at 50%, and the 10% frequency of cardiac arrest, similar to other reports.^{2,3} We found that the need for an inotropic infusion may be an indicator for risk of subsequent bradycardias, cardiac arrest and need for a cardiac pacemaker. Bradycardias were more frequent, and all asystolic cardiac arrests confined to patients in need of inotropic infusions. This may reflect a greater extent of SCI-associated cardiovascular disruption among these patients.

Pharmacological measures, such as atropine, inotropes and aminophylline,^{11,12} are drugs of choice in the management of symptomatic bradycardia. Pharmacological measures are however not always successful. The reported number of SCI patients requiring a pacemaker varies from 9 to 17%.^{2,12} similar to our 10%. Cardiac pacemakers are however not without their problems. Reported complications of patients with a cervical SCI who required a cardiac pacemaker are death during attempted insertion¹⁵ and death associated with failure of the pacemaker to capture.^{9,15} One of the three patients in our series had a pacemaker-related complication (infection), and the death of the one patient who died was not associated with the pacemaker. Drug therapies are also not problem free. For example, they may not prevent an asystolic event (in contrast to a cardiac pacemaker)¹⁶ and could be associated with other adverse consequences such as an unplanned invasive procedure.¹⁷

In our series of patients, no attempt at percutaneous cardiac pacing was undertaken. This may have been due to the success of pharmacological therapy or the need for urgent cardiopulmonary resuscitation. Percutaneous cardiac pacing is recommended as a bridge to temporary or permanent transvenous pacing for the acute management of symptomatic bradycardias, but not for asystolic cardiac arrest.¹⁸ Percutaneous cardiac pacing induces skeletal muscle contraction that has the potential to risk further injury, particularly in the presence of an unstable cervical SCI. A previous report on two patients with a cervical SCI for whom percutaneous pacing was used documented its failure, necessitating insertion of a transvenous pacemaker. On the basis of these observations, and the guidelines for advanced

life support,¹⁸ percutaneous cardiac pacing should only be considered as an emergency temporary measure until acute transvenous cardiac pacing is established.

It is not yet clear which factors are most predictive for the need of a cardiac pacemaker following an SCI. All of our patients, and many of those reported elsewhere,^{3,9,11,15,17} had a C5 or higher SCI and complete tetraplegia (ASIA-A). In addition, our patients had an anterior surgical fixation and required invasive mechanical respiratory and inotropic support. The length of the time period over which bradycardic episodes occurred was predictive for the need of a cardiac pacemaker, and to a lesser extent, a later onset of bradycardia. For the three patients with implanted pacemaker, the life-threatening events that led to the decision for a cardiac pacemaker were preceded by infrequent and unexpected episodes of bradycardia, which either reverted spontaneously, or with pharmacological interventions. This would suggest that the pattern of preceding episodes of bradycardia could not be relied upon as a predictor of future life-threatening cardiac events, or the need for a cardiac pacemaker.

It is also not clear which factors influence the decision to progress towards a permanent pacemaker following insertion of a transvenous pacemaker. Bradycardias may persist for 2 months after injury.¹⁹ Our two patients who received a permanent pacemaker required to do so at 4 weeks after injury and within 2 weeks of transvenous pacemaker insertion. One patient experienced an infection of the transvenous pacemaker, before the permanent pacemaker could be implanted. Decision to progress to a permanent pacemaker may need to be individualized based on patient and local resource considerations.

Power spectral analysis of the heart rate from such patients confirms a shift towards a predominant vagal tone on the heart rate.¹⁹ However, power spectral analysis of the heart rate has not been validated as a predictive tool for the need of a cardiac pacemaker. In a closely aligned report, fewer episodes of bradycardia were noted with the progression to spontaneous ventilation among patients with cervical SCI.²⁰ These findings may indicate that minimizing duration of mechanical respiratory support and earlier progression to spontaneous ventilation may reduce the risk for a cardiac pacemaker. In contrast all three of our patients who required a cardiac pacemaker were receiving patient-triggered, assisted ventilation. Further investigation is required to ascertain the significance of minimizing respiratory support.

In this study, patients with a cervical SCI and admitted to an ICU had a long duration of, and over half required a tracheostomy to wean from, mechanical respiratory support. Their ICU LOS is long and ICU mortality is 20%, however all ICU patients survived to hospital discharge. Of the survivors, 10% required mechanical respiratory support at the time of hospital discharge. Although only <1% of all patients with a cervical SCI required a cardiac pacemaker, there were a significant proportion (10%) of the patients with a cervical SCI that were admitted to ICU. These features would support that patients with a cervical SCI in need of ICU be managed in specialized centres, capable of inserting and managing long-term cardiac pacemakers.

The current knowledge that exists for cardiac pacemakers among patients with a cervical SCI is based on the findings from reports based on retrospective series of cases, as is ours. These reports are limited by a failure to identify all known cases, omissions in the recording of clinical information and variance in the clinical triggers for a pacemaker. Similarly each of those studies, as does ours, reports upon only a very small series of patients, being 2–5 patients, and as a consequence are of low statistical power and unable to make strong recommendations in relation to prophylactic or optimal timing of cardiac pacing. In our series of patients, all were mechanically ventilated, required inotropes and a tracheostomy to manage respiratory failure and so reflect only a small, and possibly unique, subset of all patients with a cervical SCI. The strength of our study and findings is that it confines the comparison of patients requiring pacemakers with a similar cohort of other patients (that is all mechanically ventilated, cervical SCI with motor loss and admitted to ICU).

Further reliable and clinically important investigations (for example advantages of earlier or pre-emptive use of pacemakers, identification of patients and clinical indicators for and antecedents leading up to cardiac pacing, more accurate evaluation of risk and benefits of cardiac pacing and longer-term outcomes, including that of health-associated cost benefits) are required, and will only be possible by involving a large number of sites and patients with cervical SCI. Alternatively, a systematic analysis or information from large or linked clinical data sets of patients with an SCI that includes data on the use of cardiac pacing would be required.

In summary, our findings are consistent with prior findings that the need for a cardiac pacemaker following a cervical SCI is associated with location and severity of a cervical cord injury. Furthermore, we identified that the onset and time course of bradycardic episodes may be predictive of the need for a cardiac pacemaker, particularly for patients with a cervical SCI, requiring mechanical ventilation and inotropic infusions for reasons other than bradycardias. Severe bradycardic episodes that precipitate the need for a pacemaker are unpredictable, may occur without warning and respond unpredictably to pharmacological measures. Transvenous cardiac pacing, although not without complications, is associated with a relatively good patient outcome. It is of clinical importance that such patients are managed at hospitals not only with specialized acute spinal injury services, but also with a service that provides an immediate access to cardiac pacemaker insertion and its longer-term management.

Conflict of interest

The authors declare no conflict of interest.

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