A Hemodynamic Safety Checklist Can Improve Blood Pressure Monitoring in Patients with Acute Spinal Cord Injury

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■ OBJECTIVE: **The American Association and Congress of Neurological Surgeons recommended mean arterial blood pressure (MAP) in patients with acute spinal cord injury (SCI) should be 85–90 mm Hg for the first 7 days. We evaluated whether hemodynamic management differed between a primary-receiving and tertiary hospital in the first 24 hours for patients with acute SCI and assessed whether use of a checklist could improve hemodynamic management.**

■ METHODS: **Observational review was performed of 79 patients with acute SCI before and after introduction of a blood pressure monitoring checklist and staff educational program designed to improve tertiary center management. Hemodynamic management in the primary-receiving hospital was compared with the tertiary center before and after checklist introduction.**

■ RESULTS: **At the primary-receiving center, mean number of documented MAP readings/hour was 2.2 and 3 before and after checklist introduction. The proportion having >50% of MAP recordings <80 mm Hg was 26% and 22%. The proportion having >50% of MAP recordings <70 mm Hg was 8.5% and 7%. At the tertiary center, mean number of MAP readings/hour was 1.3 and 2.7 before and after checklist introduction ($P = 0.02$). The proportion having >50% of MAP recordings <80 mm Hg decreased from 36.5% to 16% after checklist introduction ($P = 0.05$). The proportion having >50% of MAP recordings <70 mm Hg decreased from 9% to 5.5% ($P = 0.6$). Polytrauma, inotrope use, and head injury significantly correlated with low MAP recordings ($P < 0.05$). Polytrauma was an independent risk predictor for low MAP recordings ($P < 0.05$).**

■ CONCLUSIONS: **Achieving MAP targets for patients with acute SCI is challenging. Checklist use and staff education were associated with improved hemodynamic management. Presence of polytrauma identified patients at particular risk.**

INTRODUCTION

The prevalence of traumatic spinal cord injury (SCI) is estimated to be 750 per 1 million worldwide.[1] Acute trauma to the spinal cord results in an irreversible primary neurologic injury, after which a series of complex pathophysiologic processes (inflammation, ischemia, and excitotoxicity) contribute to ongoing secondary damage.[2] Neuroprotective strategies to lessen neurologic deficit are targeted at limiting effects of secondary damage. Steroid use for neuroprotection is controversial, and many centers have stopped using them.[3] Although early surgical decompression is neuroprotective in animal models of SCI,[4] there is no convincing evidence that this translates to humans; this may result from methodologic challenges with study design.[5]

Prevention of hypoxia and hypotension to limit secondary damage in the ischemic penumbra around the injured spinal cord is thought to be important for lessening severity of neurologic injury.[6-9] There is no clear consensus on what the gold standard mean arterial blood pressure (MAP) should be and for what length of time after injury this should be maintained. A systematic review by the American Association of Neurological Surgeons made level III recommendations that target MAPs in patients with acute SCI should be 85–90 mm Hg for the first 7 days.[10]

Key words
- Blood pressure
- Checklist
- MAP
- Monitoring
- Spinal cord injury

Abbreviations and Acronyms
AIS: ASIA Impairment Scale
ASIA: American Spinal Injury Association
MAP: Mean arterial blood pressure
SCI: Spinal cord injury

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Perioperative blood pressure management and achieving target MAPs for patients with acute SCI is challenging.[9] One study stressed the importance of greater awareness and vigilant perioperative management, which may necessitate inotropic support in the intensive care unit.[9] No studies have assessed how readily MAP guidelines can be adhered to in patients with acute SCI. The World Health Organization recommends routine use of a surgical safety checklist before all surgical procedures. Following introduction of the checklist in multiple centers around the world, mortality from all surgical operations significantly declined from 1.5% before the surgical safety checklist to 0.8% afterward, and inpatient complications decreased from 11% to 7%. One of the major reasons for the decline in mortality and morbidity was improved team communication and greater awareness of minimum standards of care associated with reduced complications and death from surgery.[11] Adopting this safe surgery strategy, the present observational study evaluated MAP guideline adherence in primary-receiving and tertiary hospitals in the first 24 hours for patients with acute, traumatic SCI and investigated whether use of a simple safety checklist designed to increase awareness and monitoring of blood pressure in tertiary centers may improve hemodynamic management in the first 24 hours after SCI.

MATERIALS AND METHODS

Between June 2010 and June 2014, 38 consecutive patients with acute traumatic SCI admitted to a single institution in an Australian level 1 trauma center were retrospectively reviewed. Demographics of patients in this group are shown in **Table 1**. There were 24 male and 14 female patients with a mean age of 43 years (range, 16–82 years). Twelve patients had complete injuries, and 24 had incomplete injuries. There were 25 cervical and 13 thoracic cord injuries. Inotropes were used in 14 patients. Decompressive stabilization was performed in 30 patients, and 8 patients were managed nonoperatively. The decision to perform surgery and specifics of the surgical intervention (anterior vs. posterior, number of stabilized levels) were determined by the attending spinal surgeon. In all cases, decompression was accompanied by an instrumented fusion. Eleven patients had injuries in the context of polytrauma (defined as an injury severity score >15), and 9 had associated head injuries with Glasgow Coma Scale score ≤13. All patients who received nonoperative treatment had stable injuries or were deemed unfit for a surgical procedure.

At presentation, neurologic examination was performed as per standards established by the American Spinal Injury Association (ASIA), and injury characteristics were classified according to neurologic level of injury and overall ASIA impairment scale (AIS) grade. All subjects had a baseline ASIA assessment within 24 hours of injury, followed by a 30-day ASIA assessment.

Hemodynamic management in the primary hospital and during transfer was compared with hemodynamic management in the tertiary center. Medical notes were reviewed to ascertain the mean number of documented MAP readings per hour, and the incidence of low MAP recordings (<80 mm Hg) and very low MAP recordings (<70 mm Hg). Research ethics board review considered this a performance evaluation, as this study involved observational review of routinely collected data.

Table 1. Patient Demographic and Injury Characteristics in Groups Before and After Checklist Introduction

Demographic and Injury Characteristic	Group 1: Before Checklist (n = 38)	Group 2: After Checklist (n = 41)
Number of patients	38	41
Male/female	24/14	26/15
Age, years, mean (range)	43 (16–82)	44 (18–83)
Cervical cord injuries	25 (66%)	27 (66%)
Thoracic cord injuries	13 (34%)	14 (34%)
Baseline AIS		
ASIA A	12 (31.6%)	15 (36.6%)
ASIA B	14 (36.8%)	14 (34.1%)
ASIA C	6 (15.8%)	5 (12.2%)
ASIA D	6 (15.8%)	7 (17.1%)
ASIA E	0 (0%)	0 (0%)
30-day AIS		
ASIA A	10 (26.3%)	14 (34.1%)
ASIA B	9 (23.7%)	5 (12.2%)
ASIA C	6 (15.8%)	8 (19.5%)
ASIA D	13 (34.2%)	12 (29.3%)
ASIA E	0 (0%)	0 (0%)*
Operatively treated	30 (79%)	35 (85%)
Nonoperatively treated	8 (21%)	6 (15%)
Associated head injury	9 (24%)	5 (12%)
Inotropes used	14 (37%)	14 (34%)
Polytrauma patients	11 (29%)	7 (%)

AIS, ASIA Impairment Scale; ASIA, American Spinal Injury Association.
*2 deceased.

After this initial review, measures were undertaken to improve hemodynamic management for patients with SCI referred to our institution. Quality improvement measures were targeted at the tertiary hospital, as this was where patients spent most of the first 24 hours following SCI, as evidenced by data in the first review. A hemodynamic monitoring checklist was designed and placed in the admitting on-call team rooms for staff members to become familiar with. The checklist 1) asked whether the blood pressure was being adequately monitored (minimum documentation of 2 MAP readings/hour) and 2) if low (MAP <80 mm Hg), asked whether fluid administration, intensive care, or inotropes had been considered and whether an intensive care specialist had been consulted.

Large and small group educational sessions were given to admitting on call trauma team members; emergency department and intensive care staff; and members of the operating room team, including anesthesiologists, surgeons, and nurses.

Educational sessions discussed the common causes of inadequate MAPs, discussed how the checklist could be used to prevent them, and provided a forum for questions. The fundamental premise of the checklist was to raise awareness of the need to monitor blood pressure and suggest helpful strategies for combating low blood pressure when present. Following checklist introduction and staff education, a second review was undertaken using the same methodology over a 2-year period. This review comprised 41 consecutive patients (26 male and 15 female) with mean age 44 years (range, 18–83 years) and acute traumatic SCI. Patient demographics for this group are shown in Table 1.

Of 41 patients, 15 had complete injuries, and 26 had incomplete injuries; 27 had cervical cord injuries, and 14 had thoracic cord injuries. Decompressive stabilization was performed in 35 patients, and 6 patients received nonoperative management. Eight patients had polytrauma, and 5 had associated head injuries. Inotropes were used in 14 patients. Baseline and 30-day ASIA assessments were recorded for 39 subjects, as 2 patients died of associated medical complications related to SCI before 30 days. Hemodynamic management in the primary hospital and during transfer was compared with hemodynamic management in the tertiary center. The same MAP parameters were recorded to allow comparison of hemodynamic management before and after implementation of the checklist and education program.

Statistical Analysis

Baseline differences in demographics and injury characteristics between groups before and after use of the checklist were compared using Mann-Whitney nonparametric tests for continuous data and χ^2 tests for categorical data. One-way analysis of variance was used to compare MAP readings per hour between groups before and after use of the checklist. For each patient, the percentages of low MAP recordings (<80 mm Hg) and very low MAP recordings (<70 mm Hg) were calculated. Based on these, the patient was classified into 1 of 2 categories: 1) 0%–50% of all recorded readings below threshold value (80 mm Hg or 70 mm Hg), or 2) 51%–100% of all recorded readings below threshold. This created ordinal data, which was analyzed for <80 mm Hg and <70 mm Hg separately using χ^2 test. For correlation analysis, baseline characteristics were binary coded. Age <65 years and absence of event for all other variables was coded as 0. Fisher exact or Pearson χ^2 tests were used to examine the association between baseline variables (head injury, polytrauma, age, change in AIS grade, injury level, treatment type) with incidence of low and very low MAP recordings. Variables with significant correlation were further evaluated by multinomial regression analysis. P value $\leq$ 0.05 was considered significant.

RESULTS

Baseline Differences Between Pre-Checklist and Post-Checklist Groups

There were no statistical differences between groups with respect to age (P = 0.9), sex (P = 0.9), type of injury (cervical vs. thoracic trauma) (P = 0.9), inotrope use (P = 0.8), presentation AIS grade (P = 0.9), initial treatment at primary or tertiary center (P = 0.7), surgical versus observational management (P = 0.5), presence of polytrauma (P = 0.3), or head injury (P = 0.1).

Pre-Checklist Cohort

MAP Recordings. Patients spent most of the first 24 hours in the tertiary center rather than the primary hospital or during transfer. The mean number of documented MAP readings per hour was 2.2 in the primary hospital and during transfer and 1.3 in the tertiary center, which represented a significant difference (P = 0.03).

The proportion of patients having >50% of MAP recordings <80 mm Hg was 26% and 36.5% at primary and tertiary hospitals, respectively (P = 0.34). The proportion of patients having >50% of MAP recordings <70 mm Hg was 8.5% and 9% at primary and tertiary hospitals, respectively (P = 0.99). Tables 2 and 3 compare hemodynamic management in the primary hospital and during transfer with hemodynamic management in the tertiary center before and after checklist introduction.

Neurologic Change and Associations with Low MAP Recordings. Twelve patients (32%) had improved AIS scores at 30 days, and 1 patient (2.6%) had a worse score. There was no association between change in AIS scores and presence of low or very low MAP recordings.

Post-Checklist Cohort

MAP Recordings. Patients spent most of the first 24 hours in the tertiary center rather than the primary hospital or during transfer. The mean number of documented MAP readings per hour was 3.0 in the primary hospital and during transfer and 2.7 in the tertiary center, which was not significantly different (P = 0.9). Following

Table 2. Comparison of Hemodynamic Management in First 24 Hours in Primary Hospital and During Transfer Before and After Checklist Introduction

Hemodynamic Parameter	Primary Hospital/Transfer (Pre-Checklist)	Primary Hospital/Transfer (Post-Checklist)
Mean time spent in area in first 24 hours, hours	8	6.7
Mean number of documented MAP readings per hour	2.2	3.0
Proportion of patients with documented low MAP recordings <80 mm Hg		
0% of time	40% (14/35)	41% (11/27)
0%–50% of time	34% (12/35)	37% (10/27)
51%–100% of time	26% (9/35)	22% (6/27)
Number of patients with documented very low MAP recordings <70 mm Hg		
0% of time	65.5% (23/35)	67% (18/27)
0%–50% of time	26% (9/35)	26% (7/27)
51%–100% of time	8.5% (3/35)	7% (2/27)

MAP, mean arterial blood pressure.

Table 3. Comparison of Hemodynamic Management in First 24 Hours in Tertiary Center Before and After Checklist Introduction

Hemodynamic Parameter	Tertiary Center (Pre-Checklist)	Tertiary Center (Post-Checklist)
Mean time spent in area in first 24 hours, hours	16	17.3
Mean number of documented MAP readings per hour	1.3	2.7*
Proportion of patients with documented low MAP recordings <80 mm Hg		
0% of time	18% (6/33)	38% (14/37)
0%–50% of time	45.5% (15/33)	46% (17/37)
51%–100% of time	36.5% (12/33)	16% (6/37)
Number of patients with documented very low MAP recordings <70 mm Hg		
0% of time	45.5% (15/33)	54% (20/37)
0%–50% of time	45.5% (15/33)	40.5% (15/37)
51%–100% of time	9% (3/33)	5.5% (2/37)

MAP, mean arterial blood pressure.
*$P \leq 0.05$.

checklist introduction into the tertiary center, there was a significant improvement in the mean number of documented MAP readings per hour ($P = 0.02$).

The proportion of patients having >50% of MAP recordings <80 mm Hg was 22% and 16% at primary and tertiary hospitals, respectively ($P = 0.5$). The proportion of patients having >50% of MAP recordings <70 mm Hg was 7% and 5.5% at primary and tertiary hospitals, respectively ($P = 0.4$). There was a significant reduction in the proportion of patients having >50% of MAP recordings <80 mm Hg at the tertiary hospital after checklist introduction ($P = 0.05$). There was no significant change in the proportion of patients having >50% of MAP recordings <70 mm Hg ($P = 0.6$).

Neurologic Change and Associations with Low MAP Recordings. Eleven patients (27%) had improved AIS scores at 30 days, and 1 patient (2%) had a worse score. There was no association between change in AIS scores and presence of low or very low MAP recordings.

Correlation Analysis

Patients requiring inotropes ($P < 0.01$) or with associated polytrauma ($P < 0.01$) or head injury ($P < 0.01$) were more likely to have low (<80 mm Hg) MAP recordings. Patients requiring inotropes ($P < 0.02$) or with associated polytrauma ($P < 0.01$) or head injury ($P < 0.02$) were more likely to have very low MAP recordings (<70 mm Hg). There was no significant association between MAP recordings <80 mm Hg and <70 mm Hg and age >65 years ($P = 0.08$, $P = 0.3$), injury level ($P = 0.5$, $P = 0.4$), observational or surgical management ($P = 0.8$, $P = 0.6$), initial treatment at primary or tertiary center ($P = 0.3$, $P = 0.9$), or change in AIS grade ($P = 0.8$, $P = 0.7$).

When performing multinomial regression, only polytrauma was significant for low (<80 mm Hg) and very low (<70 mm Hg) MAP recordings; both models were significant ($P < 0.01$). The relative risk for low MAP recordings in the absence of polytrauma was 0.01 (95% confidence interval, 0.001–0.126; $P < 0.01$). All patients with very low MAP recordings had polytrauma. Multinomial regression did not find head injury and inotrope use to be significantly associated with very low or low MAP recordings.

DISCUSSION

This study has demonstrated that consistently achieving MAP recordings >80 mm Hg in the first 24 hours for patients with acute SCI is challenging for the primary-receiving hospital, during transfer, and at the tertiary center. Use of a hemodynamic monitoring checklist and staff educational program designed to increase awareness about the importance of blood pressure management improved hemodynamic monitoring and control within the first 24 hours for patients with acute SCI in the tertiary center. A number of studies and guidelines[6-10] have prompted many centers to impose a target MAP of 85–90 mm Hg for patients with SCI. Strong evidence that this target MAP optimizes neurologic recovery is still needed[12]; however, there is widespread agreement that hypotension should be avoided.[13]

The first part of the study examined 2 things: first, the frequency with which blood pressure is recorded in the early period following SCI and, second, how successfully an MAP >80 mm Hg is maintained (so that hypotension is avoided). Blood pressure recording was more frequent in patients who were initially treated in a primary receiving hospital and during the transfer than when they were transferred immediately to a tertiary center. This may reflect greater awareness of the need to monitor patients' hemodynamic status in the very early period following SCI (first 8 hours) or the fact that these patients are kept in more highly monitored surroundings (the accident and emergency department or helicopter or ambulance transfer environments) for longer periods of time in the early period. The mean number of documented MAP readings per hour was 1.3 in the tertiary center, which appears low and may reflect poor documentation; however, even in highly monitored environments MAP readings have typically been recorded only each hour, even in the setting of prospective study designs.[9]

We found that 26%–36% of patients had an MAP <80 mm Hg for >50% of their total number of documented readings. This may appear alarmingly high, particularly when the target MAP should be >80 mm Hg; however, the only other study to have analyzed blood pressure control following acute SCI showed that almost all patients had MAP recordings <80 mm Hg at some point during the study, and 80% had MAP recordings <70 mm Hg.[9] There was a higher proportion of patients with suboptimal hemodynamic management at the tertiary center than when transferred from a primary receiving center. This may reflect referral patterns of patients who have potentially more severe polytrauma or that patients may be preferentially managed with relative hypotension to prevent excessive blood loss and/or clot dissolution in the polytrauma setting at the tertiary center.

Following identification of possible suboptimal hemodynamic monitoring and management, we attempted to improve management by using a checklist and educational program at the tertiary center. The rationale was that preventable adverse events are common in surgery,[14] with communication failures being the most common cause.[14] Checklists can help enable clinicians to have a structured approach to clinical problems, and many previous studies have suggested that checklists and educational programs can safeguard patient care and limit morbidity and mortality.[11,15,16]

The second part of the study demonstrated that checklist use improved hemodynamic monitoring and documentation in the tertiary center, most likely by increasing clinician awareness and vigilance. This may be explained by the Hawthorne effect, an improvement in performance due to a subject's knowledge of being observed.[17] There was also a reduction in the proportion of patients who had MAP recordings <80 mm Hg and <70 mm Hg for >50% of the time at the tertiary center. For patients who were initially triaged to the primary hospital, management remained unchanged following checklist introduction into the tertiary center as expected (26% before checklist and 22% after checklist having MAP recordings <80 mm Hg >50% of the time).

In contrast, for patients who were initially triaged to the tertiary center, their management was improved following checklist introduction into the tertiary center (36.5% before checklist and 16% after checklist having MAP recordings <80 mm Hg >50% of the time), which was significant. We did not find a statistically significant reduction in the proportion of patients having MAP recordings <70 mm Hg >50% of the time after checklist in the tertiary center, most likely because of lack of statistical power.

We identified polytrauma as an independent risk factor for MAP recordings <80 mm Hg. Therefore, clinicians caring for these patients in the trauma setting need to be particularly vigilant for hypotension. This may necessitate a low threshold for intensive care support. We did not find any association between low MAP recordings in the first 24 hours and age or change in AIS scores at 30 days. Inotrope use and head injury correlated with low MAP recordings ($P < 0.05$), but regression analysis did not find them to be independent risk factors. Inotrope use reflects detection and treatment of hypotension and is not a causative factor.

There are significant limitations to this observational study. MAP recordings are extremely variable, and with relatively infrequent recording in this study, it is not possible to say for how long patients experienced periods when MAP was <80 mm Hg. This variability is also reported in patients with traumatic brain injuries.[18] We chose to present the blood pressure data in 2 groups for ease of categorization and because the sample size was low. This oversimplifies a complex and poorly understood aspect of management for patients with traumatic SCI. There will be an inherent sampling and measurement error from multiple different health care professionals recording and documenting readings at different frequencies. We chose this method of assessment because this approximates real clinical practice. Confounding prevents any causal associations to be made. Many variables that affect outcome in acute SCI have not been included, and therefore caution must be exercised when analyzing correlations between blood pressure management and 30-day AIS.

CONCLUSIONS

There is much in the literature on timing of surgical decompression as a potential neuroprotective strategy, but very little on hemodynamic management and its role in neuroprotection due to complex challenges with study design and monitoring. This study should encourage specialist centers to assess their hemodynamic management, as suboptimal management should be identified. Education programs, checklists, and a lower threshold for intensive care unit admission may form part of a multimodal strategy to improve management when it is suboptimal. The presence of polytrauma should identify patients at particular risk of hypotension.

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