Neuroendocrine Responses to Transvascular Autonomic Modulation: A Modified Balloon Angioplasty in Multiple Sclerosis Patients

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Key words
○ autonomic function
○ balloon angioplasty
○ blood pressure
○ CCSVI
○ HPA axis
○ heart rate variability

Abstract

Balloon angioplasty (BA) is a treatment modality to correct vascular lesions in multiple sclerosis (MS) patients, who present with chronic cerebrospinal venous insufficiency (CCSVI). We hypothesized that BA clinical benefits stem in part from improvement in cardiovascular autonomic nervous system (ANS) function. We adopted the Transvascular Autonomic Modulation (TVAM), as a modified BA technique, with the objective of further enhancing ANS functional activities. TVAM involved dilation of multiple vascular beds, including IJVs, azygos and renal veins, and application of manual compression. Since the ANS regulates the function of the hypothalamus-pituitary (HPA) axis, we examined TVAM effects on HPA axis in MS patients, and determined the relationship between ANS function and HPA activity. The adrenocorticotropic hormone (ACTH) and cortisol serum levels, systolic and diastolic blood pressure (BP), and heart rate variability (HRV) parameters were measured before and 24 h after TVAM procedure in 72 MS patients. Baseline ACTH and cortisol serum levels were lower than normal ranges in 18% and 25% MS patients respectively. The intervention resulted in significant reductions in both ACTH and cortisol (p < 0.001), with a more marked ACTH reduction in males compared to females (p < 0.001). Post-TVAM BP increased in patients who presented with baseline BP within lower limits of normal ranges, but decreased in patients with baseline BP above the normal ranges. In a univariate analysis, the changes (Δ) in ACTH serum levels correlated weakly, although significantly, with Δ in diastolic BP (r = −0.265, p = 0.03), and Δ in cortisol serum levels correlated weakly, but significantly, with Δ in systolic BP (r = −0.283, p = 0.01). The observed ACTH and cortisol reductions are counter to the stress-mediated increases in serum levels of these hormones, which are expected following an invasive procedure. The clinical implications of this unexpected response warrant further investigations.

Abbreviations

ACTH Adrenocorticotropic hormone
ANS Autonomic nervous system
BA Balloon angioplasty
CCSVI Chronic cerebrospinal venous insufficiency
HPA Hypothalamus–pituitary–adrenal
MS Multiple sclerosis

Introduction

The recently set forth vascular theory of Chronic CerebroSpinal Venous Insufficiency (CCSVI) has been described as hemodynamic disturbances of the CNS venous drainage, resulting from obstructing lesions of the extra-cranial veins, particularly, the internal jugular veins (IJVs) and azygos vein [1, 2]. Although, subsequent studies have shown that CCSVI is not specific to MS [3, 4], endovascular repair, primarily balloon angioplasty (BA) of the venous lesions, has been studied as a potential MS therapeutic modality, with a documented safety profile [5–7]. Venous dilation has been shown to beneficially influence the course of MS, by reducing the rate of clinical relapse, reducing T2 lesions numbers on the MRI scan, reducing the rate of disease progression, and improving physical and cognitive function [8–10], therefore downregulating inflammatory and neurodegenerative processes. It has also been suggested that the beneficial effects of BA in MS patients is related to BA
potential for increasing the CSF flow due to improvement in venous drainage [11]. Furthermore, venous BA increases both the arterial and venous blood flow [12], correcting the hypoperfusion, which is the result of venous outflow obstructions [13]. Our recent study shows that BA has also the potential of correcting BP deviation in patients presenting with CCSVI [14]. The effect of BA on BP seems to be through the resetting of high pressure baroreceptors by sensing the degree of changes in central venous pressure; the latter is mediated via changes in volume [15]. However, venous distention could also activate the sympathetic ANS function, independent of changes in volume [16].

These results suggest that BA has the potential for improving ANS dysfunction, often observed in MS patients [17,18]. In our clinical practice, 91% patients who seek corrective BA present with a combination of internal jugular venous (IJVs) flow obstruction (≥50% unilateral or bilateral IJV closure) and clinical symptoms such as cognitive impairment, fatigue, sleeping disorders, headache upon waking up, and thermal intolerance [14]. Cardiovascular ANS dysfunction is known to contribute to these clinical symptoms [19–23], suggesting a relationship between CCSVI and ANS dysfunction.

Marchione et al. [24] have recently reported postural-dependent impairment in cerebral blood flow and cerebral venous flow in MS patients. The authors concluded that these hemodynamic impairments may stem from ANS dysfunction. ANS is known to also regulate the cerebral autoregulation and cerebrovascular tone [25]. MS patients who have ANS dysfunction [17,18] present with impairment of cerebral autoregulation [26]. The ANS vascular deregulation might in turn contribute to venous remodeling [27–30].

Based on the assumption that BA clinical benefits may stem in part from the improvement in cardiovascular ANS function due to venous dilation-induced sympathetic activation, we adopted a modified BA technique with the objective of further enhancing ANS functional activities. This modified BA technique, which we termed Transvascular Autonomic Modulation (TVAM), involves dilation of multiple vascular beds, including IJVs, azygos and renal veins, and application of manual compression. This approach assumed to result in a greater sympathetic ANS stimulation as compared to the traditional BA. Patients who underwent TVAM were selected based on the presence of ANS dysfunction rather than vascular lesions [31].

ANS activation is known to also regulate the elevation in HR and BP during physical and mental stress, via sympathetic-adrenal-medullary axis activation and catecholamine secretion [32]. Accumulated data from in vitro and in vivo studies demonstrate that catecholaminergic input through an adrenergic receptor-dependent mechanism activates the hypothalamic-pituitary-adrenal (HPA) axis, increasing the expression of the corticotropin releasing hormone (CRH) [33,34]. CRH produced in the paraventricular nucleus of the hypothalamus, in turn stimulates the secretion of the adrenocorticotropic hormone (ACTH) from the anterior lobe of the pituitary gland, which acts on the adrenal cortex to release the stress hormone, cortisol. In addition to ANS dysfunction, MS patients show alterations in the activity of the HPA axis. Both HPA axis hyperactivity [35–37] and hypoactivity [38–40] have been reported in MS patients. The hyperactivity correlates with the progression of the disease, neurological disability, and cognitive impairment [35–37]. Other studies show a negative correlation between HPA axis hypoactivity and gadolinium enhancing lesions and positive correlation with ventricular volume, and progressive disease course [38,39]. These studies collectively suggest that HPA axis dysregulation, regardless of the direction, may play a role in the pathology of MS. This study determined TVAM effect on HPA axis activity, measuring the changes in ACTH and cortisol serum levels. We also correlated between TVAM-induced changes in serum levels of the 2 hormones and changes in ANS function, measuring changes in BP and HRV parameters.

Material and Methods

Population

The study involved MS patients who visited the Endovascular Clinic (Synergy Health concepts, Newport Beach, CA, USA). A total of 72 (28 males) MS patients, average age 49.6 ± 11 years (22–72 years) and disease duration of 12.8 ± 7.7 years (1–39 years) with clinical symptoms of cognitive impairment, fatigue, sleeping disorders, headache upon waking up, and thermal intolerance. Among patients, 61 were relapsing remitting (RR), and 11 were chronic progressive (CP) (5 secondary progressive (SP), and 6 were primary progressive (PP)). Patients with hypercoaguable state and pregnant patients were excluded from the study.

TVAM deviated from traditional BA in that all of the target vessels, bilateral internal jugular, azygos and left renal vein, were treated regardless of the presence or absence of an abnormality. In this technique, vessels were treated sequentially, starting with the left jugular followed by the right jugular, azygos and finally the left renal vein. Jugular venous dilation was carried out at the level of the valve. Compression was applied during the initial 30 s of jugular balloon inflation by fluoroscopically localizing the inflated balloon in the supraclavicular fossa. Valvular localization was confirmed by IVUS. Balloon sizing was determined by vessel luminal area as calculated by IVUS. Balloon size was such that the vessel would be over-dilated 10–25% of measured area depicted by IVUS. Kevlar balloons (Bard Peripheral Vascular, Inc, 1625 West 3rd Street, Tempe, AZ 85281, USA) were utilized to deliver maximum pressure with an inflation time of 3 min, the time which was similar to that in the traditional BA procedure.

Assessment of HPA axis and ANS function

TVAM effects on HPA axis was assessed by measuring ACTH and cortisol serum levels. TVAM effects on cardiovascular ANS function was assessed by measuring BP (indicator of sympathetic activity) and R-R interval (indicator of parasympathetic activity). All measurements were performed before and 24 h post-TVAM intervention. The measurements were performed at the same time ± 2 h during the day, in a room in which the temperature was tightly regulated at 70 °C, due to thermal sensitivities of the patient population.

ACTH and cortisol serum levels were measured by electrochemiluminescence Immunoassay (ECLIA) methodology by an outside lab facility. A single measurement of systolic and diastolic BP was performed manually, by a sphygmomanometer, in sitting position. R-R interval was measured by determining the expiration/inspiration (E/I) ratio, the Valsalva ratio, and the 30:15 ponsural ratio. Deep breathing, Valsalva maneuver, and standing from a supine position were respectively used as appropriate stimuli for these tests. HRV was analyzed using the ANS 2000 (D.E. Hokanson, Inc. 12840 NE 21st Place, Bellevue, WA 98005, USA). Methods for HRV measurements have been previously described [41].
The clinical assessment of fatigue (both physical and mental fatigue) was done by the Modified Fatigue Impact Scale; cognitive impairment was defined as the loss of intellectual functions and trouble with verbal recall, basic arithmetic; concentration was measured by Perceived Deficits Questionnaire; thermal dysregulation sleeping disorder, headache upon awakening, were assessed with customized questions using a 1–5 scale for consistency.

Follow-up
Post-procedure recovery consisted of direct 2 h observation, during which time, oral administration of anticoagulation with Rivaroxaban was initiated. Rivaroxaban 15 mg/day was continued for 90 days. Jugular duplex Doppler was performed at 24 h post-procedure and at 3 months following cessation of Rivaroxaban.

Statistical analysis
All statistical analyses were performed using SPSS 14.0 for Windows (SPSS Institute, Chicago, Illinois, USA). Repeated ANOVA was used to examine the differences in ACTH/cortisol serum levels, in systolic/diastolic BP readings, and R-R intervals before and after TVAM. ANOVA also measured the differences in the measured variables between males and females, and between RRMS/CPMS patients. Multiple regressions determined the association between ACTH/cortisol and ANS function tests.

A consent form was signed by each subject before the TVAM intervention. IRB permission was obtained to allow the extraction of clinical data from patients' chart.

Results

Post-intervention adverse events
No intra-procedural adverse events occurred, specifically, no evidence of vascular injury was identified. Mild headache, mild body aches, and mild dizziness were noted in the treated group. All side effects resolved within 72 h.

ACTH and cortisol responses to TVAM

Fig. 1 shows (mean ± SEM) ACTH (Fig. 1a) and cortisol (Fig. 1b) serum levels, stratified by gender, before and after the TVAM procedure.

ACTH serum levels were reduced by 34.8 % post-TVAM intervention relative to baseline (13.8 ± 1.0 pg/ml vs. 8.0 ± 1.3 pg/ml, p < 0.001). These reductions were significant for both males (18.0 ± 2.0 pg/ml vs. 6.6 ± 1.1 pg/ml, p < 0.001) and females (11.0 ± 0.9 pg/ml vs. 9.0 ± 2.0 pg/ml, p < 0.001). Baseline ACTH serum levels (18.0 ± 2.0 pg/ml vs. 11.0 ± 1.0 pg/ml, p < 0.001), and the post-TVAM changes (Δ) in ACTH serum levels (11.2 ± 2.3 pg/ml vs. 2.2 ± 2.0 pg/ml, p < 0.001) were higher in males compared to females.

Among patients, 18.5 % (18.3 % below the normal range, 0 % above the normal range) had baseline ACTH serum levels out of the normal ranges (7.2–63.3 pg/ml). These percentages were increased to 75.3 % (68.2 % below the normal ranges, and 7.2 % above the normal ranges) post-TVAM procedure.

The reduction in ACTH and cortisol serum levels depended on the baseline levels of the 2 hormones. ACTH serum levels were reduced by 52.4 %, 46.4 %, and 77.6 % in patients with baseline ACTH serum levels ≥ 7.2–14.4 pg/ml, 14.5–21.6 pg/ml, and ≥ 21.6 pg/ml, respectively (p-values between < 0.001–0.03). However, post-TVAM reductions in ACTH serum levels were not significant in patients who had baseline ACTH serum levels below 7.2 pg/ml (16.3 % reduction, p = 0.30) (Fig. 2a).

ACTH and cortisol response subcategories

Fig. 2 presents the percent reductions in ACTH (Fig. 2a) and cortisol (Fig. 2b) serum levels, post-TVAM procedure, relative to baseline levels. These percentages are subcategorized to lower than normal range, (ACTH: <7.2 pg/ml, cortisol: <6.2 pg/ml), gradually doubling it at each subsequent level.

The reduction in ACTH and cortisol serum levels depended on the baseline levels of the 2 hormones. ACTH serum levels were reduced by 52.4 %, 46.4 %, and 77.6 % in patients with baseline ACTH serum levels ≥7.2–14.4 pg/ml, 14.5–21.6 pg/ml, and ≥ 21.6 pg/ml, respectively (p-values between <0.001–0.03). However, post-TVAM reductions in ACTH serum levels were not significant in patients who had baseline ACTH serum levels below 7.2 pg/ml (16.3 % reduction, p = 0.30) (Fig. 2a).
Cortisol serum levels were reduced by 23.5%, 49.6%, and 46.5% in patients with baseline cortisol levels > 6.2–12.4 pg/ml, 12.5–18.6 pg/ml, and > 18.6 pg/ml respectively (p-values between < 0.001–0.03), but post-TVAM reductions in cortisol serum levels were not significant in patients who had baseline cortisol serum levels below 6.2 mg/ml (14.6 % reduction, p = 0.12) (Fig. 2b). Comparison of the cortisol/ACTH ratio pre-TVAM relative to post-TVAM demonstrated a significantly lower cortisol/ACTH ratio, pre-TVAM procedure compared to the same ratio post-TVAM procedure (0.96 vs. 1.35, p < 0.002), suggesting a larger ACTH than cortisol reduction post-TVAM procedure. The differences in pre- to post-cortisol/ACTH ratio was significant in males (0.81 vs. 1.22, p = 0.20), but not in females (1.05 vs. 1.22, p = 0.003). Fig. 3 shows the mean ± SEM of ACTH (Fig. 3a) and cortisol (Fig. 3b) serum levels, stratified by disease stage, before and after TVAM procedure. The CPMS group is comprised of SPMS and PPMS patients (n = 11). The results are corrected for group differences in age, gender and disease duration. Both RRMS (14.0 ± 1.1 pg/ml vs. 8.6 ± 1.5 pg/ml, p < 0.001) and CPMS (12.8 ± 2.1 pg/ml vs. 4.8 ± 0.5 pg/ml, p = 0.005) patients showed significant reductions in ACTH serum levels post-TVAM procedure relative to baseline (Fig. 3a). In addition, both RRMS (10.8 ± 0.6 pg/ml vs. 7.8 ± 0.9 pg/ml, p < 0.001) and CPMS (10.4 ± 2.0 pg/ml vs. 4.9 ± 1.0 pg/ml, p = 0.002) patients showed significant reductions in cortisol serum levels post-TVAM procedure (Fig. 3b). Baseline and post-TVAM ACTH and cortisol serum levels tended to be lower in CPMS compared to RRMS patients, but these differences were not statistically significant (all p-values > 0.05).

Cardiovascular Autonomic Response to TVAM

BP response to TVAM

Table 1-A shows the effect of TVAM on systolic and diastolic BP. Among MS patients, the baseline systolic and diastolic BP ranged between 88 to 172 mm Hg and from 48 to 99 mm Hg respectively. TVAM reduced the total systolic BP (from 117.5 ± 2.1 mm Hg to 113.5 ± 2.1 mm Hg, p = 0.04) but not diastolic BP (from 72.2 ± 1.2 mm Hg to 72.3 ± 1.2 mm Hg, p > 0.05).

Subsequently, we categorized systolic and diastolic BP from lower than normal ranges (systolic BP: 88–105 mm Hg, diastolic BP: 48–65 mm Hg), above normal ranges (systolic BP: 116–172 mm Hg, diastolic BP: 76–99 mm Hg), and within normal ranges (systolic BP: 106–115 mm Hg, diastolic BP: 66–75 mm Hg), allowing adequate number of patients in each subcategory for optimal power analysis. This subcategorization showed multiphasic effect of TVAM on BP. At lower than normal ranges, TVAM increased both systolic (89.1 ± 1.2 mm Hg vs. 105.6 ± 2.4 mm Hg, p = 0.01) and diastolic (58.1 ± 1.3 mm Hg vs. 63.5 ± 2.3 mm Hg, p = 0.008) BP, with a more marked effect on diastolic BP. However, at above normal ranges of BP, TVAM significantly reduced the systolic (133.4 ± 2.5 mm Hg vs. 113.5 ± 2.1 mm Hg, p = 0.04) and diastolic (76.2 ± 1.2 mm Hg vs. 72.3 ± 1.2 mm Hg, p = 0.05) BP.

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vs. 123.0 ± 3.5 mm Hg, p = 0.001) but not the diastolic (84.0 ± 1.4 mm Hg vs. 81.6 ± 1.7 mm Hg, p = 0.11). TVAM had no significant effect on systolic (110.0 ± 0.7 mm Hg vs. 106.0 ± 2.4 mm Hg, p = 0.15) but reduced Valsalva ratio (1.83 ± 0.06 vs. 1.76 ± 0.05), however, none of these changes were statistically significant (p-values > 0.05).

### Discussion

We measured the activity of 2 major stress response systems, the HPA axis and the ANS, before and 24h after TVAM intervention in MS patients. This is the first study measuring endocrine responses to venous dilation in MS patients, presenting with clinical symptoms of cognitive impairment, fatigue, sleeping disorder, headache upon awakening, and thermal dysregulation, clinical symptoms which are known to involve ANS dysfunction as part of the clinical picture [19–23]. Consistent with earlier studies [38–40], we observed lower than normal baseline ACTH and cortisol serum levels in 18% and 25% of patients respectively. This hypoactivity was more pronounced during dynamic HPA responses to TVAM. In addition, the degree of post-TVAM reduction in the 2 hormones was positively associated with baseline levels of the 2 hormones.

### Study limitations

We have shown, for the first time, TVAM-induced endocrine changes in MS patients, and confirmed our earlier results on TVAM-induced changes in ANS function. However, our data is limited to one measurement before and one measurement post-TVAM intervention. We do not have long term data on these patients, and therefore one cannot determine whether changes in stress hormones are long lasting, and or influencing and

### Table 1

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<th>Pre-TVAM</th>
<th>Post-TVAM</th>
<th>p-Value</th>
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<td><strong>A. Sympathetic function</strong></td>
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<td>Systolic BP (mm Hg)</td>
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<td>Total (88–172)</td>
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<td>113.5 ± 2.1</td>
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<td>88–105</td>
<td>98.1 ± 1.2</td>
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<td>106–115</td>
<td>110.0 ± 0.7</td>
<td>106.0 ± 2.4</td>
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<td>116–172</td>
<td>133.4 ± 2.5</td>
<td>123.0 ± 3.5</td>
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<tr>
<td>Diastolic BP (mm Hg)</td>
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<tr>
<td>Total (48–99)</td>
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<td><strong>B. Parasympathetic function</strong></td>
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<td>Valsalva ratio</td>
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<td>30:15 Postural ratio</td>
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<td>1.71 ± 0.30</td>
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Abbreviations as in Fig. 1–3. E/I:Expiration/inspiration ratio.

p-Values < 0.05 are significant.
Conflict of Interest

The authors declare no conflict of interest.

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