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Original Article

Microvascular instability in tetraplegic patients: preliminary observations

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Study design: Case control.
Objectives: To describe the effect of spinal cord injury on microvascular stability.
Setting: Veterans Administration Medical Center, West Roxbury, MA, USA.
Methods: A total of 19 tetraplegic patients, aged 63±12 years, were surveyed for microvascular instability. Photoelectric pulse sensors were applied to the skin surface of the neck on both sides and to the distal pads of the left and right fourth fingers of subjects in the sitting position. All pulses during the survey periods were recorded by a polygraph system. The unstable fraction of pulsatile cutaneous blood flow (UFCF) was calculated by the sum of the periods during which pulses at any site were either half or twice the baseline amplitude divided by the survey time. Simultaneous UFCF, which was pulsatile flow change in the same direction at the same time in two leads, was also measured. Flow changes in patients with motor and sensory complete lesions were compared with incomplete lesions.
Results: Survey times were 7017±670 s. Tetraplegic complete UFCF and simultaneous UFCF were 0.25±0.12 and 0.07±0.07, respectively. Tetraplegic incomplete UFCF and simultaneous UFCF were 0.0.13±0.9 and 0.02±0.04, respectively. The differences between the groups were significant for UFCF ($P=0.04$), but not for simultaneous UFCF ($P=0.14$).
Conclusions: Tetraplegic subjects demonstrate an instability of cutaneous microvascular blood flow that is related to the severity of paralysis.
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Keywords: spinal cord injury; quadriplegia blood pressure; blood flow velocity; microcirculation

Introduction

The unstable blood pressure of the tetraplegic patient is exposed by certain stimuli that cause reflex hypertension, facial perfusion, and a risk of stroke.[1–4] This reaction is effected through the constriction of microvasculature as evidenced by a drop in skin temperature below the level of paralysis.[1] Similarly, instability is evident as postural hypotension, complicated by compromised cerebral and renal function.[5–8] The role of the microvasculature in postural hypotension in the tetraplegic patient is undetermined. Blood pressure in the tetraplegic patient during usual activities and in the absence of noxious stimuli or orthostasis is 'slightly' unstable when monitored beat to beat and compared with able-bodied subjects.[9] It is suspected, however, that blood pressure monitoring underestimates a dynamic variability of the microcirculation in tetraplegic patients. In fact, patches of changing skin temperatures below the level of paralysis in complete tetraplegia have been observed.[10] It is hypothesized that interruption of the sympathetic tracts of the cervical spinal cord as in severe tetraplegia causes an unstable vasomotor control of the microcirculation, even in the absence of noxious stimuli or body position change. It is anticipated that microvascular blood flow is less unstable when the cervical lesion is incomplete. The potential clinical applications for this concept lie in an understanding of spontaneous changes in tissue function – for example, cutaneous, nervous, renal – that can be encountered in the practice of spinal cord medicine.

Methods

Subjects

Patients with long-standing paralysis due to spinal cord injury at the tetraplegic level were recruited for monitoring pulsatile cutaneous blood flow. The subjects were described by age, level, grade and duration of

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paralysis, and by blood pressure on the day of examination. Any history of postural hypotension, dysreflexia, medical complications, or smoking was recorded. Subjects were grouped as (A) motor and sensory complete or (B) sensory or motor incomplete as the most equal division of the lesions represented.

Equipment Tranducers to measure cutaneous blood flow were made by UFI, Morro Bay, CA, USA. A photoelectric pulse with a wavelength of 950 nm is transmitted into the skin and reflected with an efficiency of 50% from a depth of 2 mm (Personal communication. UFI, Morro Bay, CA, USA). These transducers were placed on the neck at the angle of the jaw on both sides and on the distal phalangeal pads of the fourth finger of each hand. A polygraph with a strip chart recorder (Model 79E, Grass Instrument Co., Quincy, MA, USA) traced the pulsatile signals of blood flow.

Measurements Cutaneous blood flow measurements were conducted in mid morning with the subjects sitting comfortably in their wheelchairs. Recordings were collected long enough to achieve a stable baseline and then continued for approximately 30 min. The recorded pulse amplitudes were measured by hand, and amplitudes twice or half that of the baseline were marked as variations. For each patient, the seconds of variations from the baseline in each lead were summed and expressed as a fraction of the total survey time for all leads. The intended survey time was 1800 s for each lead for a total of 7200 s. The portion of the total survey time that varied by half or twice the baseline was designated as the unstable fraction of cutaneous blood flow (UFCF). In addition, significant variations in pulse amplitude in more than one lead occurring coincidentally and in the same direction were noted, summed, and designated as simultaneous UFCF. All tracing amplitudes were marked and summed by a single person. The patients were known to the grader. Baseline blood pressures were recorded for each subject.

Patients graded motor and sensory complete were compared with those with any grade of incompleteness for both UFCF and simultaneous UFCF. It was asked whether the UFCFs and simultaneous UFCF were generally higher or lower in one group versus the other. These comparisons, and the descriptive differences in the groups as well, were assessed by the Student's *t* method. The software *Primer of Biostatistics* was used to perform the calculations.[11]

Results

Subjects
In all, 19 tetraplegic patients participated; 13 were motor and sensory complete and six were incomplete. One patient who was paralyzed due to ruptured thoracic aorta had a flaccid lesion and was not included in the survey cohort. Four had a history of postural hypotension and one of severe dysreflexia. One patient had received ephedrine and one had drunk several cupfuls of coffee before testing. Monitoring time ranged from 4800 to 8160 s, mean 7017 ± 760 s. The patients are grouped and described in Table 1.

Vascular lability
Changes in pulsatile cutaneous blood flow are exemplified in Figure 1. Pulse changes were tapered or abrupt. An example of the latter is shown in Figure 2. The duration of individual periods of flow change ranged from seconds to minutes. Quantifying these changes, the UFCF was 0.245 ± 0.119 in the tetraplegic motor and sensory complete and 0.123 ± 0.088 in the tetraplegic incomplete patients, $P = 0.038$.

In the tetraplegic complete group, simultaneous blood flow changes were detected in the fingers in 17 patients (Figure 1), in the neck and a finger in four, and in the neck alone in one. Constriction of blood flow to the monitored fingers (less than half baseline) that correlated with enhanced blood flow (more than twice baseline) to the neck were looked for but not found. However, the reverse was noted. A patient with a history of postural hypotension demonstrated a period of synchronous and increased flow to the fingers correlating with reduced flow to the neck (Figure 1). The

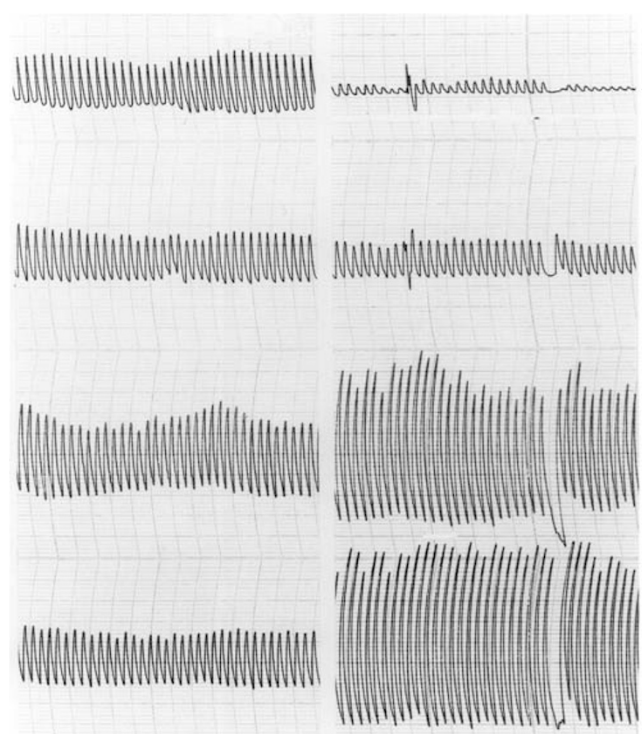

Figure 1 Cutaneous blood flow – baseline (left panel) versus mid monitoring tracing (right panel). Each panel represents 30 s of survey. Cutaneous blood flow to the neck is reduced (top tracing, right panel), while that of the fingers is increased (bottom two tracings, right)

Table 1 Characteristics and microvascular blood flow instability associated with spinal cord lesions

Patient	*Cause*	*Years paralyzed*	*Age (years)*	*SBP*	*DBP*	*Complications*	*UFCF*	*SUFCF*
C4A	Abscess	13	74	122	62		0.148	0.028
C4A	Fall	17	62	120	?	Syringomelia	0.1	0.017
C4A	mva	26	40	90	60	Postural hypotension	0.035	0.026
C5A	gsw	5	35	100	75		0.231	0.006
C5A	mva	10	76	80	0	Postural hypotension	0.388	0.087
C5A	Fall	25	67	98	80	Postural hypotension	0.255	0.089
C6A	Diving	1	58	154	76	Diabetes mellitus	0.135	0.035
C6A	mva	10	58	102	68	Syringomelia	0.209	0.063
C6A	mva	12	79	100	62		0.27	0.074
C6A	mva	22	62	120	80	Reflex hypertension	0.384	0.244
C6A	gsw	28	68	102	68	Neuropathic pain	0.309	0.015
C7A	Diving	32	60	130	70		0.368	0.184
C7A	Diving	47	53	170	70	Postural hypotension	0.398	0.055
N		13	13	13	12		13	13
Mean		19	61	114	64		0.248	0.071
SD		12.6	12.9	25.5	21.3		0.119	0.07
C4B	mva	14	62	90	60	Postural hypotension	0.104	0.043
C5B	Fall	20	68	140	70	Obesity	0.082	0.007
C5B	gsw	20	72	124	78		0.144	0.005
C6B	Diving	20	58	70	40		0.293	0.087
C2C	avm	24	76	160	90		0.065	0
C5D	mva	12	60	122	58	Diabetes mellitus	0.06	0
N		6	6	6	6		6	6
Mean		18	66	118	66		0.125	0.024
SD		4.45	7.16	32.8	17.39		0.088	0.035
P-value		0.85	0.39	0.77	0.84		0.04	0.14

Patients are listed by level and grade of paralysis. The first letter refers to the level of the lesion and the second to the American Spinal Injury Association grade for severity of the lesion (A, motor and sensory complete; B, sensory incomplete and motor complete; C, motor and sensory incomplete; and D, useful motor sparing). Causes: mva, motor vehicle accident; gsw, gunshot wound; avm, arteriovenous malformation; SBP, systolic blood pressure; DBP, diastolic blood pressure; UFCF, unstable fraction of cutaneous blood flow; SUFCF, simultaneous unstable fraction of cutaneous blood flow

simultaneous UFCF was 0.071 ± 0.07 for the tetraplegic complete and 0.024 ± 0.35 for the tetraplegic incomplete patients, $P=0.142$.

Discussion

The microvascular circulation of the skin is unstable in the tetraplegic, motor, and sensory complete patient relative to that of the tetraplegic incomplete patient. Smoking can affect the microcirculation, but the effect is transient, minutes,[12] and no patient was smoking during the test. One patient, tetraplegic complete, was known to have drunk several cups of coffee hours before testing, and the vasoconstrictive effects of caffeine may have persisted.[13] The effect of ephedrine, taken by another tetraplegic complete patient, or caffeine on vasomotor stability is unknown. Nevertheless, the unstable fractions for the tetraplegic, complete patients are predominately greater than are those of the tetraplegic incomplete patients. The vasomotor sympathetic tracts, running in the white matter of the cervical spinal cord,[14,15] may be partially spared in incomplete cervical cord lesions because the pathology is more confined, more central in location.[16] These lesions, being upper motor neuron in type, could be thought of as inducing spasticity to the sympathetic nervous system as they do for the somatic motor system.

The unstable microvascular circulation might, in fact, reflect poorly modulated subclinical stimuli – for example, contractions of the bladder against retained urine or of the colon against large bowel gas. It is interesting to note that the only patient in this series with a history of autonomic dysreflexia (severe) had by far the greatest simultaneous UFCF of the microvasculature. In the survey conducted, however, this instability at rest was generally neither massive nor coordinated and therefore not predictive of an effect on blood pressure. It coexists with another dysfunction of the microvasculature, the vascular leak and dependent edema found in spinal cord-injured and stroke patients.[17,18] It may play a role in neuropathic pain as suggested by Sherman *et al*,[10] who mapped fluctuating skin temperatures in painful sites below the level of paralysis. It might also be operative in the well-recognized variability of the renal scan.[19] The example in Figure 1 raised the possibility of steal syndromes due to spontaneous regional vasodilatation. Finally, the microvasculature of the skin might play a role in the prevention or cause of pressure sores, a function previously suggested.[20]

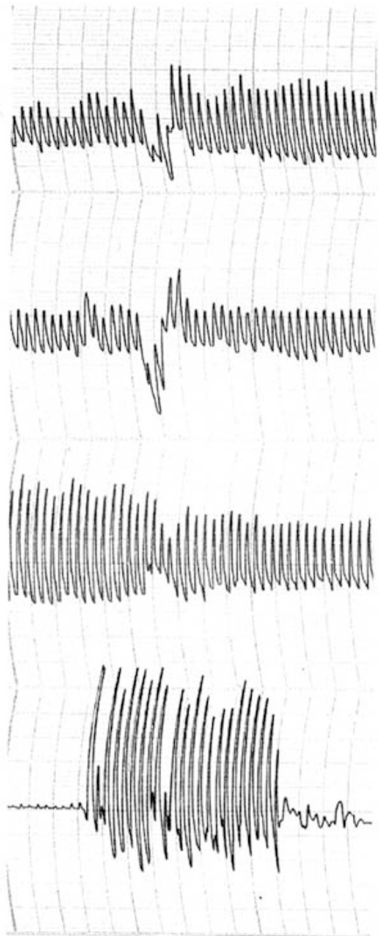

Figure 2 Cutaneous blood flow – mid survey. The panel represents 30 s of survey. Changes in blood flow to the right fourth finger (bottom tracing) are abrupt and extreme, although pulsation is maintained throughout. Changes in the upper two tracings may have been due to movement of the transducers on the neck

Conclusion

In summary, the patient with motor and sensory complete paralysis at the cervical level demonstrates a greater instability of cutaneous microcirculation than does the patient with incomplete paralysis at the cervical level. It is suggested that more extensive damage to the sympathetic tracts of the cervical cord is manifested as less vasomotor stability.

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