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ORIGINAL ARTICLE

Assessment of the sympathetic level of lesion in patients with spinal cord injury

JG Previnaire[1], JM Soler[2], W El Masri[3] and P Denys[4]

[1]Spinal Department, Centre Calvé, Fondation Hopale, Berck sur Mer, France; [2]Laboratoire d'urodynamique et de sexologie, Centre Bouffard Vercelli, Cerbère, France; [3]Midlands Centre for Spinal Injuries, RJ and AH Orthopaedic Hospital, Shropshire, UK and [4]Service de Rééducation Neurologique, Hôpital Raymond Poincaré, Garches, France

Study design: To study the vasomotor responses (skin axon-reflex vasodilatation (SkARV) to stimulation of the skin in spinal cord injury (SCI) patients.
Objective: To assess the completeness of the sympathetic injury and to define the sympathetic level of lesion in paraplegic and tetraplegic patients.
Setting: Centre Calve, Fondation Hopale and Centre Bouffard-Vercelli, France.
Subjects: A total of 81 SCI patients ranging from C2 to L2.
Method: A mechanical stimulation was applied to the skin on both sides of the trunk, using a blunt instrument. The presence of an abnormal response below the lesion helped define the sympathetic level.
Results: Above the lesion, SkARV was observed in all patients. In patients with a complete sympathetic injury, the response below the lesion was either a vasoconstrictor response in upper motor neuron lesions, or total absence of SkARV in lower motor neuron lesions. There was excellent correspondence between complete somatic (American Spinal Injury Association (ASIA) A) and complete sympathetic lesions (100% of paraplegic and 94% of tetraplegic patients), whereas an incomplete somatic (ASIA B–D) lesion was often associated with a complete sympathetic lesion. In 34% of complete ASIA A patients, a sympathetic zone of partial preservation was found, extending below the lesion on sensory denervated dermatomes.
Conclusion: SkARV is a simple bedside test that allows the assessment of sympathetic completeness of injury across the lesion as well as the excitability of the isolated spinal cord. We suggest that the definition of sympathetic level should be part of the classification of complete thoracic SCI.
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Keywords: axon-reflex vasodilatation; spinal cord injury; autonomic nervous system

Introduction

Localized vasodilatation of the skin is a physiological phenomenon that can be elicited by a variety of stimuli (thermal, mechanical, electrical and chemical). It is part of a triple response following a direct contact, first described by Lewis:[1]

- the first component was a local red reaction, which was a primary and local dilatation of the minute vessels of the skin;
- the second component, or flare, was a widespread dilatation of the neighbouring arterioles;
- the third component, or wheal (local oedema), was a local increased permeability of the vessel wall.

Whereas the first immediate reddening is a vascular reaction to the stimulus without the involvement of neuronal mechanisms, the spreading axon-reflex flare is suggested to be neurally mediated by C-fibre antidromic vasodilatation via the release of the neuropeptides substance P and calcitonin gene-related peptide.[1,2]

Thomas,[3] Guttmann and Chapelle[4,5] studied the cutaneous reflex response to determine the level of the lesion, evoking a mechanical stroke with the end of a reflex hammer across the thorax of complete spinal cord injury (SCI) patients. In chronic patients, there was a clear limitation of the flare below the lesion (dermatographia alba) in distinct contrast to the spreading flush above the lesion (dermatographia rubra). They related this diminished vasodilatation below the lesion to an increase of the sympathetic vasoconstrictor tone in the isolated cord. Skin manifestations are one of the conditions recognized in the assessment of the autonomic function in SCI patients.[6]

Our aim was to study the skin axon-reflex vasodilatation (SkARV) using a mechanical non-invasive stroke, to evaluate the segmental sympathetic vasomotor component of the skin above and below the lesion, to assess the completeness

Correspondence: Dr JG Prévinaire, Spinal Department, Centre Calvé, Fondation Hopale, 62600 Berck sur mer, France.
E-mail: previnjg@hopale.com
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of the sympathetic injury and to define a sympathetic level of lesion. This sympathetic level was then compared to the American Spinal Injury Association (ASIA) neurological level of lesion and to the ASIA Impairment Scale, to determine if they coincide or not.

Material and method

Study design

The SkARV test was performed in 81 consecutive SCI patients (34 tetraplegics and 47 paraplegics; Table 1). A mechanical stimulation was evoked by tracing a line on the skin using a blunt instrument, usually the edge of a wooden tongue depressor cut in half down the longitudinal axis. A steady pressure was applied on the skin. In all patients, the line was traced on both sides of their naked trunk, starting from the clavicle down to T12 dermatome. We then observed and compared the evolution of the SkARV on each side.

All subjects were studied lying on their back, at a comfortable ambient temperature. SkARV tests were performed either in bed or in association with urologic assessments. Bladder filling or penile vibratory stimulation (PVS) was initiated immediately after the stroke. We have repeated the examination twice in some patients. As SkARV tests are routinely performed as part of our neurological examinations, the institutional review board approval was not sought for this study.

Classification

By analogy with the International Spinal Cord Society (ISCoS)/ASIA classification,[7] we defined the sympathetic level of lesion as the most caudal segment of the spinal cord with normal sympathetic function, that is, the last trunk dermatome where a normal SkARV could be seen.

The term 'complete sympathetic injury' is used when the SkARV does not extend to T12. In patients with complete ASIA A lesions, two different situations can be identified:

- either SkARV is found on sensory dermatomes that are normally or partially innervated, that is at ASIA sensory level or within the sensory zone of partial preservation (sensory ZPP),
- or SkARV extend across the lesion on sensory denervated dermatomes. The term 'sympathetic zone of partial preservation' (sympathetic ZPP) refers to those sensory denervated dermatomes that remain sympathetically innervated.

When SkARV extend across the lesion down to T12, no sympathetic level of lesion could be defined.

Left and right sides were recorded separately, as the levels of lesion can differ by side of body. The result of the SkARV test was read and agreed upon by two individuals (the investigator and a nurse).

Patients

They were mostly traumatic SCI patients (79 out of 81 patients), aged 18 years or more, all out of spinal shock. The clinical data are reported in Table 1. The tetraplegic group included six patients with an ASIA sensory level above C4. The severity of lesion is defined according to the ISCoS/ASIA Impairment Scale as ASIA A (complete, no sensory or motor function is preserved in the sacral segments), ASIA B (incomplete, sensory but not motor function is preserved below the neurological level and includes the sacral segments), ASIA C and D (incomplete, partial motor function preserved).[7] The type of lesion referred to the level of spinal injury above or at the spinal sacral segment that did or did not induce sacral reflexes. Lesions were classified as upper motor neuron (UMN) or lower motor neuron (LMN) respectively. In this study, all UMN patients presented with some spasticity above the sacral area, whereas all LMN patients were flaccid. For the assessment of the sensory ZPP, only the thoracic segments extending from T3 to T12 (corresponding to the dermatomes were a SkARV could be seen) were taken into account.

Results

The normal SkARV consists in the combination of a flare and a local oedema (Figures 1 and 2). They both begin to appear

Table 1 Characteristics of the population

	All (n = *81*)	*Tetraplegics* (n = *34*)	*Paraplegics above T12* (n = *44*)	*Low paraplegics below T12* (n = *3*)
Age (years)	38.2 ± 10.7	35.7 ± 11.0	40.0 ± 11.0	40.9 ± 4.5
Evolution (years)	7.7 ± 6.9	5.0 ± 4.5	9.9 ± 8.4	5.1 ± 3.3
Sex	10 women	5 women	4 women	1 woman
	71 men	29 men	40 men	2 men
Type of lesion	66 UMN	33 UMN	32 UMN	1 UMN
	15 LMN	1 LMN	12 LMN	2 LMN
Severity of lesion	60 ASIA A	18 ASIA A	39 ASIA A	3 ASIA A
	9 ASIA B	8 ASIA B	1 ASIA B	—
	4 ASIA C	4 ASIA C	—	—
	8 ASIA D	4 ASIA D	4 ASIA D	—
Sensory ZPP	48 sides	6 sides	42 sides	—
	0–5 segments	1–5 segments	0–4 segments	—
	(1.6 ± 1.0)	(2.5 ± 1.4)	(1.5 ± 0.9)	—

Abbreviations: ASIA, American Spinal Injury Association; LMN, lower motor neuron; UMN, upper motor neuron; ZPP, zone of partial preservation, expressed by side of body.
Data for age and evolution are given as mean values ± standard deviations.

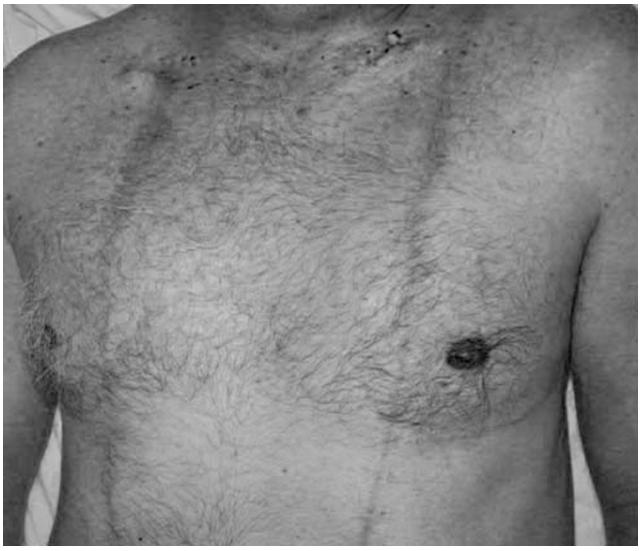

Figure 1 Skin axon-reflex vasodilatation (SkARV) test in a T3 American Spinal Injury Association (ASIA) A paraplegic patient with upper motor neuron lesion. The SkARV was normal down to T3 dermatome (sympathetic level) on right and left sides, and diminished below the lesion.

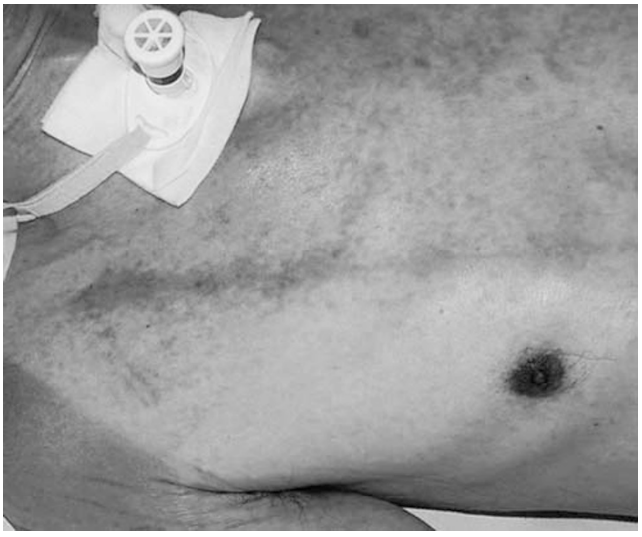

Figure 2 Skin axon-reflex vasodilatation (SkARV) test in a C4 American Spinal Injury Association (ASIA) B tetraplegic patient with upper motor neuron lesion. The SkARV was normal on the C4 dermatome, and diminished on thoracic dermatomes.

within the first minute following the stroke. The flare generally reaches its peak after 2–3 min, and then disappears progressively within 5–10 min. At its best, the width of the flare varies from as little as 1 or 2 mm to 1 cm. The oedema can last longer, up to 30 min, but is often very difficult to quantify. In our clinical practice, only the flare is taken into account for determination of sympathetic levels. For optimal SkARV interpretation, good light conditions are needed as well as careful attention during the minutes following the stroke.

SkARV above the lesion

In paraplegic patients above T12, the SkARV was always observed above the lesion. In the three patients with a complete lesion below T12, a normal SkARV was found on all thoracic dermatomes. As a rule, SkARV was usually maximal at the C4 dermatome, and decreased progressively down the thorax.

SkARV below the lesion

Complete (ASIA A) patients above T12 (Tables 2 and 3). In UMN paraplegic and tetraplegic patients, the SkARV below the lesion appeared with diminished flare and oedema (Figures 1 and 2). This vasoconstrictor response was even more pronounced when the stroke was immediately followed by PVS or cystometry (47 patients). In LMN patients, the SkARV was always absent (thin white line without flare and oedema) below the lesion.

In paraplegic patients, a complete sympathetic injury could be identified in all. The sympathetic level was identical to the ASIA sensory level in 44% of the cases (32% in UMN and 73% of LMN patients), and extended in the sensory ZPP in 22%.

In UMN tetraplegic patients, SkARV was seen in C4 dermatomes in all (Figure 2), even in individuals with very high lesions. In the C3 tetraplegic LMN patient, the SkARV was absent on the C4 dermatomes and on the thorax. A complete sympathetic injury was assessed in 94% of the tetraplegics. SkARV was limited to C4 in 44% of the cases, extended within the thoracic sensory ZPP in a further 11%.

A thoracic sympathetic ZPP was seen in 34% of all complete patients (35% of paraplegics and 33% of tetraplegics), extending from 1 to 6 dermatomes (mean 2.2 ± 1.1).

Incomplete (ASIA B–D) patients above T12. A complete sympathetic injury was assessed in 55% of the cases (40% of paraplegics and 59% of tetraplegics): in 24% of cases, SkARV was limited to C4 (tetraplegics) or at the ASIA sensory level (paraplegics), and in 31% it extended from 2 to 6 thoracic dermatomes (mean 2.6 ± 1.9) (Table 4).

The SkARV could be retested once in 35 patients (15 tetraplegics and 20 paraplegics) at a 10–30 days interval: the same sympathetic levels were seen in 97% of cases, 3% (one patient) presented a discrepancy limited to one dermatome.

Discussion

The main findings of this study are threefold:

(1) There is an excellent correspondence between complete somatic (ASIA A) and complete sympathetic lesions (100% of paraplegics and 94% of tetraplegics), whereas an incomplete somatic (ASIA B–D) lesion is associated with a complete sympathetic lesion in 55% of cases.
(2) However, in 34% of complete ASIA A patients, discrepancies between neurological and autonomic levels of lesion were found, with presence of a sympathetic ZPP extending to a few segments on sensory denervated dermatomes.

Table 2 Distribution of the sympathetic levels in complete ASIA A patients

Type of lesion	*Same level*	*S+1*	*S+2*	*S+3*	*S+4–5*	*No sympathetic level*	*Absent SkARV*	*Total*
Paraplegia (above T12)								
UMN	18	19	7	9	3	—		56
LMN	16	2	4	—	—	—		22
n	***34***	***21***	***11***	***9***	***3***	—	—	***78***
	C4	T3	T4	T5	T6–8	No sympathetic level	Absent SkARV	Total
Tetraplegia								
UMN	16	1	4	10	1	2	—	34
LMN	—	—	—	—	—	—	2	2
n	***16***	***1***	***4***	***10***	***1***	***2***	***2***	***36***

Abbreviations: LMN, lower motor neuron; SkARV, skin axon-reflex vasodilatation; UMN, upper motor neuron.
Same level: identical sensory and sympathetic levels in paraplegics.
S+1 to S+5: difference by which the sympathetic level exceeded the sensory level, expressed as number of dermatome(s).
T3–T8: location of the sympathetic levels in tetraplegics.
No sympathetic level: normal SkARV down to T12 dermatome.
Italic bold values represent the sum of each semi-column.

Table 3 Distribution of sympathetic levels in relation with sensory ZPP in complete ASIA A patients

	Location of SkARV					*Total*
	Normally innervated skin	*Sensory impaired skin (ZPP)*	*Sensory denervated skin*	*No sympathetic level*	*Absence of SkARV*	
Paraplegics						
Absence of sensory ZPP	18	—	18	—	—	36
Presence of sensory ZPP	16	17	9	—	—	42
n	***34 (43.6%)***	***17 (21.8%)***	***27 (34.6%)***	—	—	***78 (100%)***
Tetraplegics						
Absence of sensory ZPP	16	—	10	2	2	30
Presence of sensory ZPP	—	4	2	—	—	6
n	***16 (44.4%)***	***4 (11.1%)***	***12 (33.3%)***	***2 (5.6%)***	***2 (5.6%)***	***36 (100%)***
Total	**50 (43.9%)**	**21 (18.4%)**	**39 (34.2%)**	**2 (1.8%)**	**2 (1.8%)**	**114 (100%)**

Abbreviations: SkARV, skin axon-reflex vasodilatation; ZPP, zone of partial preservation.
Normally innervated skin: corresponds to the sensory level in paraplegics, and C4 dermatomes in tetraplegics.
No sympathetic level: normal SkARV down to T12 dermatome.
Normally innervated skin: corresponds to the sensory level in paraplegics, and C4 dermatomes in tetraplegics.
Bold values represent the sum of each full column.
Italic bold values represent the sum of each semi-column.

(3) Sympathetic responses below the lesion vary according to the type of lesion (vasoconstrictor response in UMN and absent response in LMN lesions), reflecting the excitability of the isolated spinal cord.

The definition of an sympathetic level on thoracic dermatomes is made possible by the segmental distribution of the sympathetic outflow to the skin: the preganglionic neurons leave the intermediolateral cell column with the thoracic ventral roots, exit via the white rami communicantes and synapse in the thoracic paravertebral ganglia at the same level (11 thoracic ganglia are identified on both sides of the spinal cord); the postganglionic axons then link up with the corresponding segmental spinal nerves via the grey rami communicantes. Some sympathetic preganglionic axons can pass up or down several segments of the sympathetic chain before synapsing, or synapse with several postganglionic neurons. These fibres eventually supply secretory fibres to sweat glands, motor fibres to the smooth muscle of the hair follicles and to the smooth muscle of the blood vessels of the limbs and abdominal wall.[3,8] Clinical studies in complete SCI patients confirmed that at each thoracic segment sympathetic neurons and spinal nerves innervate the same thoracic dermatome.[3–5]

We showed an exact correspondence between the sympathetic and the ASIA sensory levels in 44% of complete paraplegics above T12. Such correspondence is not possible in complete tetraplegics, as the sympathetic thoracic column is totally disconnected from cerebral control. In these cases, the cervical dermatomes are innervated by sympathetic fibres originating below the lesion (Figure 3).[3] Coincidence between thoracic sensory ZPP and SkARV was found in a further 18% of all complete patients.

Discrepancy between neurological and autonomic functions (sympathetic ZPP) was found in 34% of complete ASIA A patients, with SkARV extending below the lesion on denervated dermatomes, and was even more frequent in incomplete ASIA B–D patients. The preservation of sympa-

Table 4 Distribution of the sympathetic levels in incomplete (ASIA B–D) patients

Severity of lesion	*Type of lesion*	*Same level*	*S+2*	*S+3*	*S+4*	*No sympathetic level*	*Total*
Paraplegics (above T12)							
ASIA B	LMN	—	—	—	—	2	2
ASIA D	UMN	2	1	—	1	4	8
	n	***2***	***1***	—	***1***	***6***	***10***
		C4	T4	T5	T6–8	No sympathetic level	Total
Tetraplegics							
ASIA B	UMN	6	6	1	1	2	16
ASIA C	UMN	2	—	—	—	6	8
ASIA D	UMN	—	2	1	—	5	8
	n	***8***	***8***	***2***	***1***	***13***	***32***
Total	**n**	**10 (23.8%)**	**9**	**2**	**2**	**19 (45.2%)**	**42 (100%)**

Abbreviations: ASIA, American Spinal Injury Association; LMN, lower motor neuron lesion; UMN, upper motor neuron lesion.
Same level: identical sensory and sympathetic levels in paraplegics.
S+2 to S+ 4: difference by which the sympathetic level exceeded the sensory level, expressed as number of dermatome(s).
T4–T8: location of the sympathetic levels in tetraplegics.
No sympathetic level: normal SkARV down to T12 dermatome.
Bold values represent the sum of each full column.
Italic bold values represent the sum of each semi-column.

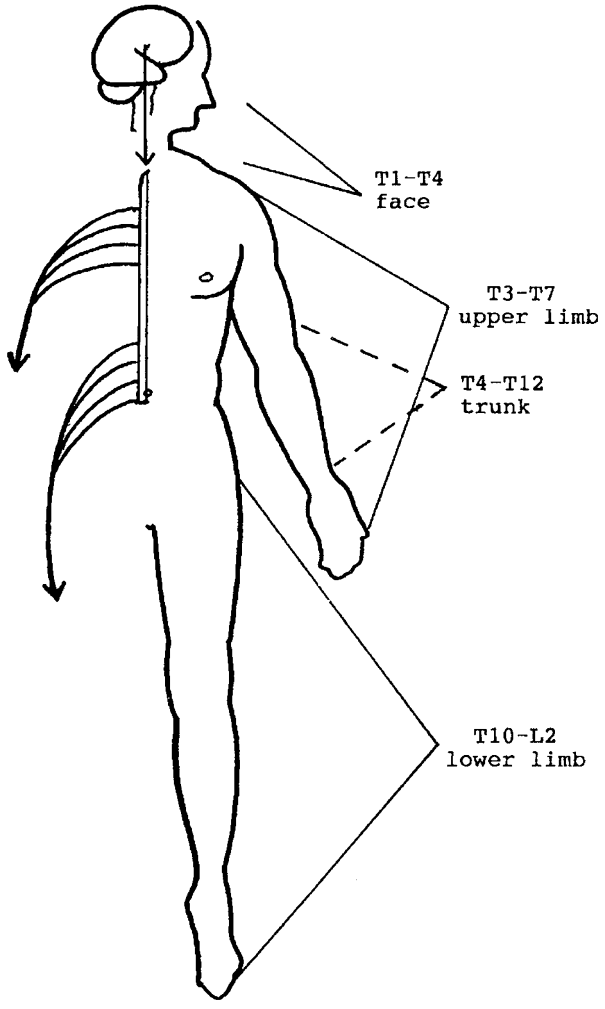

Figure 3 Sympathetic innervation of the skin by cord segments.

thetic pathways across the injury, even if limited to a few spinal segments, could have clinical implications, depending upon the localization and the extent of the remaining autonomic control. The T1–T5 and T5–T10 sympathetic outflows project respectively to the heart and to the large splanchnic circulatory bed, and are directly implicated in the cardiovascular control (autonomic dysreflexia, orthostatic hypotension and so on);[9,10] sympathetic fibres arising from T10 to L2 are involved in sphincteric functions (psychogenic erection, ejaculation, bladder neck dyssynergia and so on).[11–14] Our findings suggest that the assessment of sympathetic levels and sympathetic ZPP provides additional aid to the classification of thoracic SCI patients.

Below the lesion, a sympathetic vasoconstrictor response was seen in all complete ASIA A patients with a UMN lesion. As all our patients were examined after the acute phase,[6,15] this indicates that vasodilatation can be modulated by sympathetic function below the lesion. The isolated spinal cord may produce an increased tone in the vasculature, which reduces the vasodilatation, or it reacts with increased outflow and enhanced vasoconstriction in response to the sensory stimulus, that is, a focal autonomic dysreflexia.[1,2] Whether this decreased SkARV below the lesion is due to increased vasoconstriction or reduced vasodilatation is debatable.[2,4,10,16]

On the opposite, vasodilatation but not vasoconstrictor responses were seen below the lesion at the C4 dermatomes in all complete UMN tetraplegics, even in high C2–C3 patients. Vasodilatation above the lesion has been already described as part of autonomic dysreflexia, and includes flushing of the head or nasal obstruction (Guttmann's sign).[4,17]

No response (white line without flare and oedema) could be elicited below the level in patients with complete LMN lesions, which is suggestive of destruction of the

corresponding spinal segments. As the state of excitability of the isolated spinal cord influences the autonomic reactions below the level,[9,10,14,15] it is our view that the classification of SCI should always take the type of lesion (UMN or LMN) into account.

Interestingly, we found a more intense sympathetic vasoconstrictor response below the lesion when SkARV test was associated with PVS or cystometry. These procedures stimulate the sympathetic nervous system, and can produce autonomic dysreflexia, with paroxysmal rise in both systolic and diastolic blood pressure, mostly in patients with lesion above T6.[11,14,15,17] The widespread involvement of the vasculature below the lesion suggests the spread of neuronal impulses intraspinally, resulting in a marked reduction in peripheral blood flow, which may result in cold limbs.[15] As the pressor stimuli below the lesion add sensitivity to the SkARV test,[5] we recommend its association with clinical tests, such as PVS, cystometry, cutaneous cold[18] or electrical stimulation.[10]

Admittedly, SkARV test has its limitations: it is only suggested as a simple bedside clinical test. It does not allow the full assessment of the integrity of the sympathetic pathways. The flare interpretation is only qualitative and may be difficult to read in the presence of a dark skin complexion. SkARV test would benefit from an assessment of skin temperature, as well as quantification of the pressure applied to the skin during the stroke, as both may have an impact on vasodilatation. More sophisticated techniques, such as laser Doppler flowmetry, are able to quantify and compare the change in skin blood flow above and below the lesion.[2,16]

There are numerous studies evaluating the sympathetic cholinergic component of sweat function. They have used the sympathetic skin responses (SSRs), a non-invasive technique that assesses sympathetic cholinergic sudomotor pathways. The SSR is a reflection of the integrity of sympathetic cholinergic pathways to sweat glands above and below the lesion.[11,19] As these SSRs cannot be recorded at the thoracic level, the galvanic skin response might represent an alternative.[20] Other tests have been developed to assess the cutaneous sympathetic adrenergic system. SkARV and vasomotor responses can be evoked above and below the level of lesion in trunk dermatomes, using physiological stimulus such as local heating,[16] electrical stimulation[10] or more invasively with intradermal injection of histamine.[2] They all reported diminished vasodilatation below the level of lesion.

Conclusion

SkARV is a simple bedside test, consistent and reproducible over time, which can be used in clinical routine. It allows the assessment of sympathetic completeness of injury across the lesion as well as the excitability of the isolated spinal cord.

Detailed assessments of the neurological function of SCI persons in conjunction with their autonomic function will increase our awareness and ability to treat the autonomic consequences of SCI.[12] We suggest that the definition of sympathetic level should be part of the classification of complete ASIA A thoracic SCI.

Further studies are needed to correlate the level and completeness of sympathetic lesion with clinical findings.

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