
Sympathetic reflex control of subcutaneous blood flow in tetraplegic man during postural changes

K. SKAGEN, K. JENSEN, O. HENRIKSEN AND L. KNUDSEN
Department of Medicine II, Kommunehospitalet, Copenhagen, Department of Clinical Physiology, Bispebjerg Hospital, Copenhagen, and Fysiurgisk Hospital, Hornbæk, Denmark

(Received 26 January/10 August 1981; accepted 14 December 1981)

Summary

1. The effect of head-up tilt upon subcutaneous blood flow in the distal arm and leg was studied in 12 patients with complete traumatic spinal cord transection at the cervical level.

2. Blood flow was measured by the local 133Xe washout technique.

3. Leg lowering induced a 47% decrease in blood flow in the distal leg. During head-up tilt (45°) blood flow in the leg decreased by 48%. In the arm remaining at heart level blood flow decreased by 37% during tilt and this vasoconstriction could be prevented by nervous blockade with lignocaine injected subcutaneously 5 cm proximally to the labelled area. Leg blood flow was unaltered by proximal blockade but could be blocked by local infiltration in the labelled area with lignocaine in low doses.

4. Head-up tilt of tetraplegic patients induced vasoconstriction in the subcutaneous tissue of the forearm, which could be prevented by proximal blockade. Thus the vasoconstriction could be due to a spinal sympathetic reflex mechanism. This as well as local mechanisms including the veno-arteriolar reflex may play a role in recovery of arterial blood pressure during head-up tilt in the tetraplegic patient.

Key words: blood flow, head-up tilt, nervous blockade, skin, spinal reflex, tetraplegia, vasoconstrictor response, veno-arteriolar reflex.

Introduction

The maintenance of blood pressure during passive head-up tilt depends upon a compensatory increase in total vascular resistance. The arteriolar constriction underlying the increase in vascular resistance in normal man is due to a sympathetic reflex mechanism involving centres located proximal to the spinal cord [1]. Patients with high spinal cord transection may show orthostatic hypotension because of an interruption of the normal baroreceptor reflex [2]. However, in the chronic phase these patients are able to sit without signs of orthostatic hypotension [3, 4]. This suggests that circulatory adaptation to loss of the normal baroreceptor reflex has developed. It is therefore possible that reflex control of blood pressure develops at a spinal level. Animal experiments have indicated that there is reflex circulatory regulation at spinal cord level [5, 6]. In tetraplegic man, marked elevation of both systolic and diastolic blood pressure during cutaneous, visceral and muscle stimulation have been thought to be the result of sympathetic spinal reflex activity [7–11]. However, reflex homeostatic regulation of blood pressure during postural changes has not been conclusively demonstrated in tetraplegic man. Humoral agents may play an important role in homeostatic regulation of blood pressure. An exaggerated increase in plasma renin activity and concentration in response to head-up tilt in tetraplegic patients has been reported [12, 13]. Guttman et al. [2] found a smaller increase in catecholamine levels on head-up tilt in tetraplegic patients than in normal subjects, and Sharpey-Shaffer [14] proposed that in tetraplegic man...
patients there might be a return of vascular tone, owing to increased sensitivity to circulating humoral agents.

In normal subjects Henriksen [15] found a local sympathetic veno-arteriolar reflex mechanism elicited by an increase in venous transmural pressure of 25 mmHg or more. This reflex was not influenced by acute spinal blockade [16] and could therefore be active in blood pressure regulation in tetraplegic patients.

The aim of this study was to investigate the effect of passive head-up tilt on vascular tone in subcutaneous tissue in tetraplegic man. It was also our intention to clarify whether or not spinal and local sympathetic reflex mechanisms are involved during postural changes in tetraplegic man.

**Material and methods**

**Material**

Twelve tetraplegic patients (11 males, mean age 29 years, range 19–49 years, and 1 woman, 44 years), from whom informed consent was obtained, were studied. These patients had physiologically complete traumatic spinal cord transection at the cervical level (C4–C6) of more than 1 year.

During this study they received no medication but underwent intensive physiotherapy. All had urinary catheters and none had signs of active infection or bed sores. All patients were in normal state of hydration and nutrition.

**Methods**

Subcutaneous blood flow was measured by the local $^{133}$Xe washout technique as previously described [17] and expressed in the same units.

Arterial blood pressure was measured with a sphygmmomanometer and a 15 cm × 36 cm arm cuff on the arm not used for measurements of blood flow. The diastolic pressure was determined as the Korotkoff sound 4 and the mean arterial blood pressure was estimated as diastolic pressure + ½ (pulse pressure). The blood pressure was given as the mean of three measurements obtained within the last 5 min of each investigation.

Heart rate was obtained by counting the arterial pulse rate at the wrist for 1 min.

**Procedure**

The patients were placed in the supine position 1 h before investigation. Constant room temperature was approximately 22°C. Before the actual measurements began, patients were restrained by belts around the chest, thighs and calves. The urinary bladder was emptied and the catheter kept open during the investigation to avoid visceral reflexes. $^{133}$Xe [3 mCi/ml in sodium chloride solution (154 mmol/l: saline)] was injected (0.1–0.2 ml) slowly subcutaneously 5 cm proximal to the wrist and 5 cm proximal to the lateral malleolus of the leg on the same side.

Relative vascular resistance, $R_{test}/R_{ref.}$, was calculated from the obtained relative blood flows, $f_{test}/f_{ref.}$, and estimated arterial and venous mean pressures.

A single investigation consisted of three to five measurements each lasting 6–10 min on arm and leg respectively with the $^{133}$Xe-labelled area in the following positions: (1) supine position, arm and leg at heart level (reference level); (2) the $^{133}$Xe-labelled area on the leg lowered 40 cm or more below reference level, arm remaining at heart level; (3) leg and arm at reference level; (4) passive head-up tilt (45°C), arm remaining at heart level; (5) supine position, arm and leg at reference level.

The effects of proximal nervous blockade on the vascular response to passive head-up tilt in the leg and arm were determined in positions (3)–(5) as described in a previous study [17]. An injection of 5–10 ml of lignocaine (1%) was given into the subcutaneous tissue in a V-shape 5 cm proximally and laterally to the labelled area.

The effects of local nervous blockade during positions (3), (4) and (5) were determined by infiltration of the labelled field on the leg with 1–2 ml of lignocaine (0.3 mmol/l; 0.001%) [18].

Results are given as mean values ± 1 SEM.

**Statistics**

Student’s $t$-test for paired samples was used to assess significance ($P < 0.05$ significant).

**Results**

**Central haemodynamics**

Table 1 shows the effect in seven patients of leg lowering and head-up tilt on arterial blood pressure and heart rate before and during local nervous blockade of the leg and proximal nervous blockade of the arm. All measurements remained unchanged when the leg was lowered. However, head-up tilt caused a significant change in systolic pressure, pulse pressure, mean arterial blood pressure and heart rate.

During a combination of head-up tilt, local
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TABLE I. Effect of leg lowering and head-up tilt on arterial blood pressures and heart rate before and during nervous blockade in tetraplegic patients

Left: results before nervous blockade. Right: results obtained during nervous blockade of the 133Xe-labelled areas of the arm and the leg (see the text). Values are expressed as means ± SEM (n = 7). To assess significance, values obtained under test conditions were compared with the means of the values just before and after the test (*P < 0.02; **P < 0.001).

<table>
<thead>
<tr>
<th>Blood pressure (mmHg)</th>
<th>Leg lowering and head-up tilt</th>
<th>Head-up tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arm</td>
<td>Leg</td>
</tr>
<tr>
<td>Systolic</td>
<td>114 ± 3</td>
<td>106 ± 3</td>
</tr>
<tr>
<td>Diastolic</td>
<td>74 ± 2</td>
<td>71 ± 3</td>
</tr>
<tr>
<td>Pulse</td>
<td>39 ± 3</td>
<td>35 ± 5</td>
</tr>
<tr>
<td>Mean</td>
<td>87 ± 2</td>
<td>83 ± 3</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>57 ± 4</td>
<td>55 ± 3</td>
</tr>
</tbody>
</table>

Fig. 1. Effect of leg lowering and head-up tilt before and during nervous blockade of the subcutaneous blood flow (Jtest/Jref.) and relative vascular resistance (Rtest/Rref.) in the arm (□) and the leg (□) of tetraplegic patients. Jtest/Jref. is the ratio between blood flow obtained during leg lowering or head-up tilt and average blood flow measured during reference conditions just before and after the test. Rtest/Rref. is the corresponding calculated vascular resistance. Vertical lines with bars denote 1 SEM. Figures denote the number of patients.

Local veno-arteriolar reflex

In seven patients subcutaneous blood flow in the leg decreased by 47% (P < 0.001) when the leg was lowered 40 cm, corresponding to an increase in vascular resistance of 98% (P < 0.005) (Fig. 1).

Head-up tilt (45°)

During head-up tilt of the seven patients subcutaneous blood flow in the leg decreased by 47% (P < 0.001), corresponding to an increase in vascular resistance of 70% (P < 0.02) (Fig. 1). In the same patients blood flow in the arm remaining at heart level during tilt decreased by 37% (P < 0.001), corresponding to an increase in vascular resistance of 42% (P < 0.02) (Fig. 1).

Head-up tilt and proximal nervous blockade

The effect of proximal nervous blockade on the vasoconstrictor response to head-up tilt was investigated in the arm and the leg respectively 10 min after injection of lignocaine.

In the same seven patients, during proximal nervous blockade no vasoconstriction could be demonstrated in the arm during head-up tilt; blood flow decreased by 1% (P > 0.5) and vascular resistance decreased by 11% (P > 0.05) (Fig. 1). In five other patients subcutaneous blood flow in the leg decreased by 50% (P < 0.001) during proximal nervous blockade and tilt, corresponding to an increase in vascular resistance of 71% (P < 0.02).

There was no difference in the vascular changes were observed during head-up tilt before and during proximal nervous blockade of the leg (Fig. 1).
response to head-up tilt in the leg before and during proximal nervous blockade \( (P > 0.9) \).

**Head-up tilt and local nervous blockade**

In the seven patients, the responses of the subcutaneous vascular bed in the leg to local infiltration of the labelled area with lignocaine \((0.3 \text{ mmol/l})\) were investigated during head-up tilt (Fig. 1).

Before the local nervous blockade head-up tilt induced a decrease in subcutaneous blood flow in the leg of \(43\% \) \((P < 0.001)\), corresponding to an increase in vascular resistance of \(72\% \) \((P < 0.005)\).

During local nervous blockade head-up tilt did not induce any significant decrease in blood flow \((P > 0.1)\) or vascular resistance \((P > 0.2)\). Thus the effects of head-up tilt in the two aforementioned set of conditions were significantly different \((P < 0.02)\).

**Discussion**

Passive head-up tilting \((45^\circ \text{C})\) of a normal subject causes insignificant changes in systolic, diastolic and mean arterial blood pressure but a significant increase in heart rate \([1, 19]\). Tilting of a tetraplegic patient causes a fall in systolic, diastolic, pulse and mean arterial pressure and an increase in heart rate \([2, 11, 20]\). Our results are in agreement with these observations.

Peripheral blood flow has seldom been measured in tetraplegic patients during tilt. Corbett et al. \([20]\) suggested that the observed decrease in forearm blood flow was at least partly due to active reflexes. Similar active vasoconstrictor reflexes have been demonstrated during postural changes in normal man \([21]\) and are thought to be due to reflexes from low-pressure baroreceptors in the intrathoracic vascular bed \([22]\) involving supraspinal pathways \([23]\).

In the present study, vasoconstriction in the arm induced by head-up tilt could be blocked by proximal nervous blockade. This suggests that a sympathetic nervous reflex at the spinal level leads to peripheral vasoconstriction in response to head-up tilt in tetraplegic patients. The very fact that the vasoconstriction could be abolished by proximal nervous blockade rules out a humoral mechanism although humoral factors may play a role in other vascular beds.

Viscero-cutaneous stimulation may result in marked spinal reflex discharge and this may have contributed to the present findings. However, this seems unlikely because the increased vascular resistance in the tilted position remained constant and the blood pressure was without fluctuations throughout the investigation period.

The local veno-arteriolar reflex was found in the tetraplegic patients to the same extent as in normal subjects. Thus subcutaneous blood flow decreased by approximately \(50\%\) when the leg alone was lowered \(40\text{ cm}\). The reflex was unaltered by tilt, since nervous blockade \(5\text{ cm}\) proximal to the labelled area did not prevent this vasoconstriction.

However, infiltration of the \(^{133}\text{Xe}\)-labelled area on the dependent leg with lignocaine in low doses (which do not affect myogenic activity \([18, 24]\)) completely abolished the vasoconstrictor response. This seems to exclude an increase in inherent myogenic activity, which elevates the level of the basal vascular tone \([25–27]\), as a mechanism of the vasoconstriction during tilt in tetraplegic subjects.

**Conclusion**

This study presents evidence in support of the existence of a spinal postural cardiovascular reflex in tetraplegic man. This mechanism, together with the local veno-arteriolar reflex, might be responsible for the ability of tetraplegic man to manage orthostatic manoeuvres without fainting, although these mechanisms cannot prevent a certain degree of orthostatic hypotension.

**Acknowledgments**

This study was supported by grants from the Michaelson Foundation, Copenhagen, Denmark.

**References**


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