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Cold-stress tests involving finger skin temperature measurement for evaluation of vascular disorders in hand-arm vibration syndrome: review of the literature

Received: 11 September 2000 / Accepted: 9 May 2001 / Published online: 11 October 2001
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Abstract Cold-stress tests are used for evaluating vascular disorders in the hand-arm vibration syndrome, and the value of such tests based on finger skin temperature measurement has been investigated. However, there is a wide difference in the test conditions among countries and researchers. Standardization of the cold-stress tests is currently under discussion within the International Organization for Standardization. We reviewed various aspects of the cold-stress tests involving finger skin temperature measurement, including water temperature, hand immersion time and other test conditions, and evaluated their diagnostic significance. Water temperature varied from 0 °C to 15 °C and hand immersion time varied from 0.5 min to 20 min. The cold-stress tests are associated with relatively severe suffering, thus, higher temperature of cold water and shorter time of immersion are desirable. To date, however, there has not been sufficient data indicating diagnostic value in a test method involving cold water at around 15 °C. Diagnostic value is also influenced by other test conditions, such as room temperature, season, use of ischemia during immersion. For standardization of the cold-stress test involving finger skin temperature measurement, these factors must be considered together with water temperature and immersion time.

Keywords Hand-arm vibration syndrome · Cold-stress test · Finger skin temperature · Test condition · Standardization

Introduction

Standardization of a vascular assessment method for the hand-arm vibration syndrome is currently under discussion within the International Organization for Standardization (ISO/TC108/SC4/WG11 1996). The method constitutes measurement of finger skin temperature and finger systolic blood pressure during cold-stress test. For the cold-stress test involving finger skin temperature measurement, one or two hands are immersed in cold water and finger skin temperatures from pre-immersion to post-immersion are evaluated. Various test conditions such as water temperature, hand immersion time, evaluation parameter for diagnosis, have been investigated in Europe, North America and Asia.

Since the extensive discussions of diagnosis and preventive methods for the hand-arm vibration syndrome were initiated in the 1960s, various tests for evaluating the abnormality of peripheral circulation in the affected fingers have been investigated by many researchers in Japan. We previously reviewed the research findings concerning finger skin temperature measurement during the cold-stress test, especially test conditions that influence the test results and the diagnostic significance (Harada et al. 1999). The aim of the present paper is to review cold-stress test methods involving finger skin temperature measurement from countries other than Japan and to discuss their diagnostic significance with respect to various test conditions together with research findings already reported from Japan.

Pathophysiological aspects of finger skin temperature measurement

A typical symptom of the hand-arm vibration syndrome is vibration-induced white finger (VWF). The phenomenon of VWF is caused by sudden interruption in blood flow, particularly in the superficial cutaneous capillaries of the finger. This decrease in blood flow may be caused by hyperactivity of the sympathetic nervous system...
(Harada 1994) as well as by a local mechanism such as hypertrophy of arterial walls (Takeuchi et al. 1986; Hashiguchi et al. 1994).

At earlier studies, various trials of provocation of VWF by cold exposure have been attempted (Okada et al. 1967); however, white finger attack was not induced in 100% of patients with a history of VWF, and it was feared that the abnormal vasoconstriction reflex might be intensified by these procedures. Consequently, cold-stress tests not aimed at inducing white finger attack have been investigated for detecting peripheral circulatory disturbance of the affected fingers.

In contrast to the finger systolic blood pressure test involving digit cooling, the finger skin temperature test involving immersion of a hand in cold water does not correlate well with VWF (Virokannas et al. 1991; Kurozawa et al. 1991). The finger systolic blood pressure is measured during cooling whilst the finger skin temperature is measured before, during and after cooling. The finger systolic blood pressure can sensitively reflect interruption of digital blood flow. It is pointed out that the finger systolic blood pressure test reflects the vasoconstriction phase and the finger skin temperature test reflects the vasodilatation phase (Virokannas et al. 1991).

A lower finger skin temperature is also expected to reflect a persistent abnormality of blood flow in fingers affected by the hand-arm vibration syndrome. Many workers exposed to vibration complain of a cold sensation in the fingers and hands in daily life (Ishitate et al. 1992). The symptom of cold sensation is caused by the persistent decrease in arterial blood flow in the fingers and hands. Cold-stress test stimulating the sympathetic tonus based on finger skin temperature measurement could improve diagnosis of this abnormality.

### Cold-stress tests involving finger skin temperature measurement investigated in Japan

Thirty-three publications on the cold-stress tests investigated in Japan are listed in Table 1. These papers were reviewed previously (Harada et al. 1999). Water temperature and hand immersion time used by researchers in these studies have varied considerably from 0°C for 30 s to 15°C for 10 min. As a result of discussions among Japanese researchers, a water temperature of 5°C and an immersion time of 10 min were considered most suitable for diagnosing the hand-arm vibration syndrome. As to room temperature, a range from 20°C to 23°C was generally accepted. The Japanese Ministry of Labor accepted the cold-stress test method as criteria for compensation for affected workers in 1975 (Labor Standards Bureau 1975).

However, the use of water at 10°C became more prevalent during these 20 years; the reason was that suffering during the cold-stress test with water at 5°C was severe. Several studies compared results of the cold-stress tests with water at 5°C and water at 10°C.

### Table 1  Publications on cold-stress tests in Japan. All studies were reviewed in Harada et al. 1999

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Temperature</th>
<th>Author(s)</th>
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| 1976 | Iwata H (0°C-30 s, 5°C-5 min) | 1982 | Saito K et al. 
| 1967 | Okada A et al. (4°C-1 min) | 1883 | Miyashita K |
| 1968 | Iwata H a,b, Futatsuka M a, Iwata H a,b | 1984 | Sato S et al. a, Harada N et al. b, Miyashita K et al. a,b, Kurumatani N et al. b, Harada N et al. b |
| 1971 | Okada A et al. (4°C-15 min) | 1986 | Osaki J et al. a, Chang CP a,b |
| 1977 | Yamada S et al. a, Matsumoto T et al. b | 1989 | Tomida K et al. a,b, Harada N et al. b |
| 1980 | Saito K et al. b, Azuma T a,b (15°C-10 min) | 1991 | Matoba T et al. a,b, Harada N et al. b |
| 1981 | Kasamatsu T et al. b, Matsumoto T et al. b, Kurumatani N et al. b, Sakakibara H et al. a,b, Harada N et al. a,b | 1992 | Ishitate T et al. b, (4°C-1 min) |

*In English

a 5°C-10 min
b 10°C-10 min

Although the diagnostic value of the cold-stress test with 5°C water was relatively greater than that of the test with 10°C water, the 10°C water test was judged to be acceptable, based on a positive correlation in finger skin temperature between tests and reduced subject suffering (Harada et al. 1999).

### Water temperature and immersion time with respect to diagnostic significance

Published reports on various methods used in cold-stress tests involving finger skin temperature measurement with respect to diagnostic significance are summarized in Table 2. Twenty-three studies from 22 papers are listed in order from lowest to highest water temperature and from longest to shortest immersion time. The paper by Hack et al. (1986) has two parts in Table 2. As shown in Table 1, many papers about the cold-stress test were published in Japan, and after many trials of cold-stress tests involving finger skin temperature measurement, immersion of one hand in 10°C water for 10 min is a widely accepted method, currently. As this is the representative test method in Japan, a review paper only summarizing the method (Harada et al. 1999) is cited in Table 2.

Among these 23 studies, water temperature and hand immersion time varied considerably from 5°C for 20 min to 15°C for 10 min. Because suffering during the cold-stress test is severe, higher temperatures of cold water and shorter times of immersion have been tried recently. Ischemia procedure during immersion was