Standardization of Finger Systolic Blood Pressure (FSBP) Cooling Tests

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Abstract

A finger systolic blood pressure (FSBP) cooling test was introduced in 1977 and standardized during the following years for the optimal provocation and best characterization of an attack of vasospastic Raynaud's phenomenon (RP). The purpose of the present review is to compare and analyse some different techniques used in FSBP cooling tests from different countries and described in the final draft of the international standard, ISO/DIS 14835-2 (2004). The selected FSBP test results indicate to some extent that the tests are reliable and have acceptable diagnostic values despite the use of different techniques to obtain them. However, only a few studies used a zero-pressure FSBP%(0) to verify an ongoing attack of vasospastic RP. Most studies used an abnormal cold reaction FSBP%(A), located below the lower limit of controls, to make the anamnestic diagnosis of RP probable. According to the ISO draft, different types of finger cooling and body thermostating can be used together in the seated or supine position, and FSBP%(A) is indicated to be used for diagnostic purposes. Further studies are recommended to solve future standardization problems not included in the upcoming ISO standard. An international agreement on the presentation and comparison of test results is needed as a supplement to ISO/DIS 14835-2.

Key words: cold provocation test, finger systolic blood pressure, Raynaud's phenomenon, standardization, vibration-induced white finger

Introduction

It is widely accepted that a medical interview is the best method of diagnosing Raynaud's phenomenon (RP) in subjects with vibration-induced white finger (VWF) caused by exposure to hand-arm vibration (1, 2). However, it is of importance to use an objective test for the diagnosis and classification of RP; medical treatment; advice on continuation or change of employment; medico-legal purposes concerning compensation for occupational disease and re-education; scientific research on RP. Before 1977, RP was most often diagnosed through medical interview and possibly a hand cooling test for provoking an RP attack, diagnosed by visual inspection of the characteristic colours of RP on cooled fingers. However, it has been found very difficult to provoke an RP attack by hand cooling tests in the laboratory, whereas the finger colour of RP is easily recognized during an attack (3).

A finger systolic blood pressure (FSBP) cooling test was

introduced in 1977 (4). The test was developed and standardized in the following years for the optimal provocation and characterization of an attack of vasospastic RP (5–7). This test is termed the original FSBP cooling test. Different versions of the original test have been used in several countries. Some different techniques of the test were standardized in 2004 and positioned in a final draft for an international standard termed ISO/DIS 14385-2 (8). The draft is expected to become an international standard in the near future.

The purpose of the present review is to 1) describe and analyse the underlying basis of the original FSBP cooling test; 2) compare the original test with a hand cooling test that detects the finger colour of RP; 3) compare the original test with other published versions of the FSBP test; 4) compare the techniques of the original FSBP cooling test with the techniques used in the final ISO draft; and 5) describe some standardization problems derived from the techniques standardized in ISO/DIS 14835-2 (8).

Medical interview

The nosographic sensitivity and specificity of a medical interview are 100% if the interview is defined as the true method of reference. However, finger colour of RP has been

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observed by hand cooling tests in anamnestic non-affected phalanges in subjects with and without RP (3, 9, 10). A medical interview is therefore not a true method of reference in such cases. An interview has high 5-year reproducibility in diagnosing RP at a given time, the kappa coefficient being +0.94 (3).

The severity of RP was previously graded according to Taylor-Pelmeur stage assessment (2); however, in 1986, it was proposed to be graded according to the revised scale termed the "Stockholm Workshop scale for VWF 1986" (11). A subject with ischemic signs on finger skin under warm conditions or gangrene of the fingers probably has a disease other than the advanced but rarely seen stage 4 of VWF (12).

Measurement of systolic blood pressure

An indirect measurement of systolic blood pressures on the upper arm (ASBP) and ipsilateral fingers (FSBP) can be performed to detect organic obstructions of circulatory significance in digital or more proximal arteries (13). Comparisons with arteriographic findings have shown that FSBP or FSBP-ASBP is decreased only if arteries in or leading to both sides of the finger are occluded, the sensitivity being about 85% (14, 15). Thus, a normal pressure gradient is measured if at least one obstruction-free arterial path leads to and through the finger (15). Bilateral arterial occlusions distal to the sensor of pressure detection are not recognized by the pressure method.

ASBP is measured by auscultation using a 12-cm broad cuff that encircles the upper arm. ASBP is very close to the intra-arterially measured pressure in normal-sized healthy or hypertonic subjects (16).

FSBP is measured with an inflatable plastic cuff in velcro encircling the proximal phalanx of the thumb or the intermediate phalanx of the second finger to the fourth finger, using a mercury-in-silastic strain gauge on the outer phalanx to detect the initial systolic inflow of blood (17). Assuming the systolic pressures of these fingers to be identical and close to ASBP in healthy subjects under thermoneutral conditions (18), a 24-mm-wide cuff is used on non-thermostated fingers (17) and a 30-mm-wide double inlet cuff is used on fingers thermostated during 5 min ischemia (5). FSBP can be measured precisely, the within-day and between-day variation coefficients being about 5% and 10%, respectively (5). It is a prerequisite for recording systolic blood pressures with cuff techniques that the arteries compressed by the cuff are perfectly collapsible tubes that open up when minimal positive transmural pressure is established (13). If the arterial wall is subjected to extensive sclerosis, the indirectly recorded systolic pressure exceeds the intraluminal pressure (13). However, this has been found to be quite rare in the hands and fingers. If the artery is constricted, the true systolic pressure will be underestimated by indirect recordings (18). This is a normal finding when finger arteries are exposed to cold (5, 6). In this situation, the decrease in FSBP is equal to the increase in arterial wall tone (4).

Original FSBP cooling test

1. Local finger cooling

A FSBP cooling test was introduced by Nielsen and

Lassen in 1977 (4). The local cooling of a finger was performed at standardized temperatures during 5-min ischemia to thermostat the digital arterial wall at the applied temperatures. The 5-min cooling period is obviously short enough to escape the provocation of the cold-induced periodic vasodilations termed the Hunting reaction (19). The middle phalanx of the anamnestic most affected finger was thermostated at 30°C (20), 15 and 10°C or 6°C (4, 6, 7). FSBP was measured at the lower temperatures with the same cuff and strain gauge as used at 30°C. Correction for changes in the perfusion pressure of the hand during the investigation was based on the simultaneous measurements of FSBP on a noncooled ipsilateral finger without anamnestic RP, usually the thumb. The indirectly recorded decrease in FSBP, which is observed when the finger is cooled from 30 to 15 and 10°C, is explainable by transmural pressure that is necessary to reopen the constricted artery during the deflation of the cuff. This decrease in FSBP reflects an increase in the tone of the digital arterial wall (4).

2. Combined finger cooling and body cooling

The subject investigated is lying in the supine position and dressed in his usual indoor clothing during a combined finger cooling and body cooling. Standardized body cooling is performed with a cooling blanket perfused with cold tap water (8°C–12°C) about 1 hr before the body cooling to secure a constant cooling temperature. The cooling blanket covers the whole anterior and lateral surfaces of the body from the toes to the armpits. Head, neck, arms and hands are uncovered. The hand tested is placed on towels rolled as a cylindrical cushion upon the blanket with both arms on each side of the body. In this position the fingers investigated should be located at the level of the midaxillary line, that is defined to be the heart level, and without touching the cooling blanket, bed or cushion. Body cooling is performed 15 min before the thermostating of the finger is started and continues during the whole investigation. The given technique for body cooling was introduced in 1978 by Nielsen and has since been used in studying indoor-working young females (5). Body cooling has been used in studying vibration-exposed outdoor working men since 1979 (6). It was observed that FSBP%(15°C) decreased in a female with primary RP when the room temperature was reduced from 25 to 20°C and showed a zero pressure at a room temperature of 5°C (5). Using the combined finger and body cooling, it was found that FSBP%(15°C) differed between women with primary RP, cold-handed women, and women without finger symptoms (5, 20). Another study performed with the combined finger and body cooling showed that FSBP%(15°C) differed between men with VWF, vibration-exposed men without RP, and controls without finger symptoms and who use no vibrating hand tools (21). Furthermore, the study showed that FSBP%(6°C) in vibration-exposed men without finger symptoms was lower in men with an exposure period of 10–23 years than in men with an exposure period of 1–3 years (21). During the combined finger and body cooling, the vasoconstrictor effect of the sympathetic nervous system was about 2–3 times as high as the local vasoconstrictor effect in subjects with primary RP and vasospastic VWF (22, 23). The results indicate that the sympathetic nervous system plays a dominant role in the

establishment of an RP attack.

The total effects of applied body cooling are as follows: a sensation of coolness but without freezing or shivering from cold during the investigation; an increased and standardized sympathetic vasoconstrictor activity; a better separation of FSBP test results between subject groups with different finger symptoms; a detection of subclinical abnormal test results; and an increased detection of true-positive zero pressures.

3. Diagnostic values of original FSBP cooling test

The between-day variation coefficient of FSBP%(15°C) is about 10% in normal women (5). The within-day variation coefficients of FSBP% are 8.7% at 15°C and 10.2% at 6°C in chain saw operators (21). Thus, FSBP% is a precise measure of cold-induced arterial vasoconstriction. The lower normal 95% confidence limits of FSBP% were 68% at 15°C and 58% at 6°C in outdoor-working men (21). An RP attack is verified as a zero blood pressure, FSBP%(0) (5, 24). The gap of FSBP% between zero and lower normal limits makes it possible to detect an abnormal reaction, FSBP%(A), in subjects with and without RP. FSBP%(A) values higher than zero may be registered in subjects with anamnestic RP but no provoked RP attack, subjects with exaggerated subclinical cold reaction but without anamnestic RP, and subjects with a false-positive test. In selected studies, the FSBP%(0) test had a nosographic sensitivity of 86%–92% in vibration-exposed men with anamnestic RP and a specificity of 81%–100% in vibration-exposed men without anamnestic RP, whereas the FSBP%(A) test had a sensitivity of 99%–100% and a specificity of 58%–94% (6, 21, 25). The false-negative results of FSBP%(0) did not significantly correspond with those in cases of milder VWF and can not exclude the existence of RP in subjects with a positive history of VWF (3).

In contrast to findings obtained by indirectly recorded digital blood flow (26) and digital pulse volume (24), FSBP measurement can be precisely performed on cooled fingers. The main reason for this difference in recording methods is probably that the sensor of FSBP recordings is based on detecting the nonpulsatile aspects of blood inflow (13).

Original FSBP cooling test and a finger colour test

The original FSBP test has been compared with a hand cooling test that detects finger colours of RP in a single comparative study (3). The hand was cooled during 5-min ischemia in water of 10°C. Finger colours of the cooled hand were evaluated by direct visual inspection (FCV) and by a blind judgment of a slide of the photographed cooled hand (FCS). Both cooling tests were performed during body cooling and applied to the same groups of subjects. FCS had a 3-week variation coefficient of 0.93 in diagnosing RP. This indicates that the RP colour is easy to recognize once an RP attack has appeared. The sensitivities were 57% (FCV), 61% (FCS), 74% (FSBP%(0)), and 96% (FSBP%(A)) in 23 subjects with anamnestic VWF. The specificities were 93% (FCV), 91% (FCS), 88% (FSBP%(0)), and 64% (FSBP%(A)) in 56 vibration-exposed subjects without anamnestic RP. The sensitivity and specificity did not differ significantly between FSBP%(0), FCS and FCV,

maybe because of the small number of subjects. Six of the seven men with a false-positive zero pressure also had a positive FCV or FCS, and the seventh had a history of active VWF. It therefore seems reasonable to assume that these test results indicate that all seven men had a true positive FSBP%(0). If so, FSBP%(0) had a specificity of 100%. An FSBP%(A) range of 0%–57% had a higher sensitivity and a lower specificity than FSBP%(0). Only one subject with anamnestic RP had a false-negative FSBP%(A). A zero pressure verifies an RP attack, whereas an abnormal FSBP% above zero only indicates a higher or lower probability of an anamnestic true RP or a probability of anamnestic symptomless fingers.

The advantages of the finger colour test are its direct visualization of an RP attack, use of inexpensive equipment, and the simplicity, which are suitable for both field and laboratory studies. The disadvantages are its relatively low sensitivity and often painful cooling procedures.

The advantages of the original FSBP cooling test using the combined finger and body cooling are its standardized and tolerable cooling procedures, acceptable sensitivity in detection of an RP attack as a zero pressure, and a reliable quantitative measure of arterial tone which makes it possible to detect abnormal cold reactions and changes in reactions (3, 27). The disadvantages of the method are its expensive equipment, complicated and time-consuming performance (investigating only one finger at a time), and demand for experienced investigators. This makes the test most suitable for investigations of individuals and a small group of subjects in special laboratories. FSBP%(0) should be used in individual cases in which the detection of an RP attack is demanded. FSBP%(A) may be suitable to discriminate between larger groups of subjects with and without anamnestic VWF (28).

Original FSBP cooling test and other versions of this test

FSBP% is independent of age in normal men who have never worked with vibrating hand tools (21, 29, 30). In vibration-exposed subjects, the variation coefficient of FSBP% was approximately 12% in tests without body cooling (29, 31), which was of the same magnitude as the 8–10% of the original test performed with body cooling (21). The lowest normal limits of FSBP% at 15, 10 or 6°C were 61% at a room temperature of 16°C with no cooling blanket (32), and 60% at room temperatures of 21–23°C and no body cooling (33, 34), which are of the same size as 58% at room temperatures of 15 and 19°C with the use of cooling blanket in an original test (6, 7, 21, 25). The lower limits of 62%–58% at 15–10°C were found in a study testing four fingers at a time, without body cooling and room temperature is unknown (30). Thus the lowest normal limit of FSBP% was about 60% at finger temperatures of 15–10–6°C in the original test and its three different versions, and performed by four independent research groups from Denmark, Sweden, Italy, and England. The lower normal limit of FSBP% in a Japanese study was 90% for a finger at cooling temperature of 10°C at a room temperature of 26°C with no cooling blanket (35); the higher limit may probably be

caused by the use of a higher room temperature.

The FSBP%(0) of vibration-exposed men had a sensitivity of 70% and a specificity of 97% in a FSBP test using finger cooling at 5°C and nonspecific body cooling (36). In comparison, an original test seemed to have a higher sensitivity of 86% but the same specificity of 100% (25). The FSBP(A) of vibration-exposed men had a sensitivity of 74–86% in tests not using a cooling blanket which seems lower than 99% found in the original test whereas the specificities of 88–100% and 94%, respectively, which were of the same size (25, 32–35, 37). However, it was a common experience among investigators that the provocation of a zero pressure is difficult to obtain and requires an experienced investigator (personal communication).

Techniques used in final draft of ISO/DIS 14835-2 (2004)

The final draft standard, ISO/DIS 14835-2 (2004), is exclusively concerned with the measurement and evaluation of FSBP cooling tests (8). It is mentioned in the draft that the concrete reference values of controls should be measured in each single laboratory. Local finger cooling from 30°C to 15 and 10°C during 5 min of ischemia is used in the draft as in the original test (5–7). The same formula for FSBP% calculation with correction for changes of hand systolic blood pressure during the investigation is used in the draft and original test. A room temperature of 21°C±1°C seems to be acceptable in comparison with the temperatures used in the original test (5, 21, 25).

1. Techniques of finger cooling

Two important techniques in the draft have to be discussed in detail. The first technique concerns the method of the simultaneous measurement of FSBP on four tested fingers of a hand and the use of the remaining finger as reference. The lowest normal limit (58%) obtained by this technique is of the same size as that obtained in FSBP tests cooling only one finger (30). FSBP% findings in such finger cooling in vibration-exposed subjects with and without RP have not been obtained by the present author in scientific journals. It is recommended in the ISO draft that as many fingers as possible should be investigated. The use of the new and the original techniques of local finger cooling, and the investigation of one, more than one or all fingers will make it difficult to compare findings in different laboratories. An international agreement on how to present and compare such results is not included in the draft but will be of great importance to draw. The simultaneous cooling of four fingers may give an FSBP% of each single finger that is different from the FSBP% obtained by cooling one finger at a time in the same vibration-exposed subject.

2. Body cooling

The second technique to be discussed is body cooling. The recommendation in the draft is that “finger cooling without body cooling is preferred but body cooling may be used”. No arguments are given for this preference in the draft. In contrast to the draft, the original method implies the use of body cooling with a cooling blanket as previously mentioned, in both women

(5) and men (6). To the author's knowledge from personal experience, body cooling is not tolerated among English and Italian men because of the sensation of a very uncomfortable strong cooling. The mild body cooling used in the original test just gives a feeling of coolness and is well tolerated among Danish indoor-working women and outdoor-working men (3, 5, 6, 21, 25). It is possible that subjects from other countries with other geographical climates have limits for an unacceptable sensation of cold other than those found in Denmark. Another explanation may be that body cooling has been too cold compared with the original body cooling used in Denmark and causes freezing and shivering from cold instead of a sensation of mild coolness.

A disadvantage of using body cooling with a cooling blanket is that the investigation has to be performed with the subject in the supine position whereas investigations without use of a cooling blanket easily are performed with the subject seated in a comfortable position. The advantages of the original body cooling are its higher sensitivity in RP diagnosis, a better separation between groups with different finger symptoms, a detection of subclinical abnormalities, and an increased number of true-positive FSBP%(0) test results. It is suggested that a cooling blanket be used if an RP attack is demanded for diagnostic, therapeutic, medico-legal or scientific reasons; however, it may be omitted in other situations.

Discussion

The FSBP cooling test was introduced as a test using the local cooling of one finger with FSBP measurement by the cuff and strain gauge technique during 5 min of finger ischemia (4). It was developed and standardized to become a test using combined finger and body cooling (5–7). This original FSBP cooling test makes it possible to confirm an RP attack as a zero pressure and to distinguish between cold reactions measured in subjects with anamnestic VWF, vibration-exposed subjects without anamnestic RP and normal controls. It has a variation coefficient of 10% and acceptable diagnostic values, which makes the test suitable for diagnostics and follow-up studies. These findings have to some extent been confirmed by several independent research groups using modified versions of the original test.

A technique involving the simultaneous cooling of four fingers has recently been introduced (30). Its lower normal limits are the same size as those obtained by cooling only one finger in other studies, but have not been compared with findings in vibration-exposed subjects with and without RP. A draft of the international standard, ISO/DIS 14835-2 (2004), concerning the measurement and evaluation of FSBP cooling tests, is expected to become an international standard in the near future (8). According to the draft, the following techniques can be used: cooling of one finger at a time or up to four fingers simultaneously with or without body cooling in a seated or supine position with a sensation of thermal comfort or coolness. Furthermore, the classification of test results may be possible using FSBP%(A) or FSBP%(0).

All the possibilities of combining different techniques can make it difficult to compare findings in the same subjects

measured using different versions of the original cooling test. Further studies are recommended to solve standardization problems not discussed in the ISO draft. An international

agreement on indications for different test techniques and on the classification, presentation and comparison of test results is needed as a supplement to ISO/DIS 14835-2 (2004).

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